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Linking physics labwork activities to their potential learning outcomes - does a declaration make a difference?

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Research literature as well as teachers and students have persistently questioned the learning potentials of laboratory work as long as it has been a part of the teaching of physics.

This dissertation investigates how to link physics laboratory work activities in the Gymnasium and the potential learning outcomes of such activities, as well as examining if a declaration make a difference; that is if there exist a correlation between the teachers' level of declaration of their intended learning outcomes and how the students engage in and reflect upon the laboratory work activities. The examination is founded on four different empirical studies.

The potential learning outcomes of laboratory work activities are investigated through a number of sources (research literature, curricula, etc.), which sums up to a six-fold categorization scheme: *the conceptual domain*, *the procedural skills domain*, *the enquiry domain*, *the nature of science domain*, *the scientific attitudes domain*, and *the affective domain*. Each of these general categories is investigated in order to clarify their content, and their validity as potential learning outcomes of labwork activities is discussed. Thereafter six types of labwork activities are recognized, each having one of the six labwork purposes as their main aim. These labwork types are: *Experiences, exercises, investigations, meta-tasks, vague problems,* and *Christmas experiments*. The potentials of each labwork type are investigated in order to clarify their possible secondary purposes, leading on to a scheme linking labwork types to (general) labwork purposes.

Using this as a framework for investigating specific labwork activities, a series of typical physics labwork activities used in the Danish Gymnasium is developed on the basis of different sources, such as collected labguide series, student assignment databases, etc. All of these commonly used labwork activities are recognized to be the *exercises* labwork type, therefore serving the primary purpose in the procedural skills domain. All labwork activities are analyzed in order to clarify their potentials in relation to sub-skills of the procedural skills domain, thereby linking the most commonly used labwork activities to their specific potential learning outcomes.

Taking of from this normative and descriptive analysis of labwork activities and their potential learning outcomes, a number of empirical studies are done in order to investigate what happens if the teachers do or do not declare their intentions with their specific labwork activities. Two types of studies are done: 'naturalistic' and 'experimental' case studies. For the naturalistic cases, two teachers' and their students' work in the school laboratory were observed without direct interference of the design or implementation. It was recognized how the teachers' declaration level differed significantly. For the experimental cases, two teachers were each asked to perform two similar labwork activities to the same group of students within the same physics topic, but with very different levels of declaration. These four cases show a significant correlation both quantitative and qualitative between the declaration level and the way the students articulate their reflections about the labwork during the activity, as well in the quality of their lab reports.

For Nanna, Esben and Ebbe

Resumé

Forskningslitteraturen såvel som lærere og elever har vedholdende stillet spørgsmålstegn ved læringspotentialerne for laboratoriearbejde så længe det har været en del af undervisningen af fysik.

Denne afhandling analyserer hvordan man kan sammenkæde laboratoriearbejde i fysik med de potentielle læringsudbytter, der findes for sådanne aktiviteter, samt undersøger hvorvidt en deklaration gør en forskel, dvs. om der eksisterer en korrelation mellem lærernes deklarationsgrad af deres tilsigtede læringsudbytter og hvordan eleverne engagerer sig i og reflekterer over laboratoriearbejdet. Undersøgelsen bygger på fire empiriske studier.

De potentielle læringsudbytter af laboratoriearbejde er analyseret ved hjælp af en række kilder (forskningslitteratur, læreplaner, etc.), og opsummeres i et skema med seks kategorier: *det konceptuelle domæne*, *det procedurale domæne*, *domænet for forskende undersøgelser*, *det perspektiverende domæne*, *domænet for videnskabelige holdninger* og *det affektive domæne*. Alle disse generelle kategorier er undersøgt for at afklare deres indhold, og deres validitet som potentielle læringsudbytter for laboratoriearbejde er diskuteret. Derefter genkendes seks forskellige typer af laboratoriearbejde, hver havende et af de seks formål som deres hovedrationale. Disse laboratorietyper er: *erfaringer*, *øvelser*, *undersøgelser*, *metaopgaver*, *vagt formulerede problemer* og *juleforsøg*. Potentialerne for hver af disse undersøges for at afklare deres mulige sekundære formål. Dette leder til et skema der sammenkæder laboratorietyper med de (generelle) laboratorieformål.

Ved at bruge dette som ramme for en undersøgelse af specifikke laboratoriearbejder udarbejdes ved hjælp af en række kilder (såsom indsamlede forsøgsvejledninger, databaser for skoleopgaver, etc.) en serie af typiske fysikforsøg ofte benyttet i det danske gymnasium. Hver af disse ofte benyttede forsøg genkendes som øvelsestypen *opgave*, hvormed deres primære formål findes i det procedurale domæne. Alle forsøgene analyseres for at afklare deres potentialer i relation til de færdigheder, der findes i det procedurale domæne, hvormed de oftest brugte laboratoriearbejder sammenkædes med deres specifikke potentielle læringsudbytter.

Ved brug ad denne normative og deskriptive analyse af forsøg og deres potentielle læringsudbytter er et antal empiriske studier er foretaget for at undersøge hvad der sker, hvis lærerne deklarerer eller ikke deklarerer deres intentioner med specifikke forsøg. To typer af studier er foretaget: 'naturalistiske' og 'eksperimentelle' casestudier. I de naturalistiske cases er to læreres og deres elevers arbejde i laboratoriet observeret uden direkte indblanding i hverken design eller implementering. Lærernes deklarationsgrad var meget forskellig for de to cases. I de eksperimentelle cases er to lærere hver blevet bedt om at udføre to forsøg med den samme gruppe af elever og indenfor det samme fysikemne, men med meget forskellig deklarationsgrader. Disse fire cases viser både kvantitativt og kvalitativt en signifikant korrelation mellem deklarationsgraden og den måde eleverne artikulerer deres refleksioner om forsøget under selve laboratoriearbejdet, samt i kvaliteten af deres forsøgsrapporter.

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Part I

Introduction to the study

1 Impetus and focus

I wish to initiate this thesis with a quote from a physics teacher in the Danish Gymnasium[1]. The quote is part of an email correspondence concerning a request of visiting his physics classroom to do laboratory work observations. The visit was rejected due to practical reasons[2]. Still I wish to display the quote, since it has continuously set me in a tragicomic mood, which has inspired me to pursue. The quote is:

> To be honest I don't think that deliberate, didactic thoughts take up a lot of space in the minds of teachers in physics. So if you wish to interview a representative group of people from the breed of physics teachers, many of them will - if you do not stop them in their venture - make up didactical reflections for the occasion. I do not think the reason for this lack of deliberate thoughts (if my hypothesis is correct) is that we/they do not want to or are not able to have deliberate didactical thoughts. I think most physics teachers are lead by habit, intuition, scarcity and the overload of demands (especially those of bureaucracy), which just does not make room for the luxury of having didactical thoughts. At least for my own concern I often wonder just how few didactical thoughts guide my own teaching (including laboratory work); even though I think I am good at it and think it makes sense to take the trouble to have these thoughts. Often it is all about getting through the gap in the hedge or finding the correct strategy of survival. The gap between theoretical and practical pedagogy is according to my experience often separated by several decades of lightyears.
>
> (Physics teacher in the Gymnasium, own translation)

This quote is a nice departure for my thesis work. Teachers apparently have - if this teacher's hypothesis is to some extent generalizable - problems finding the room for didactical thoughts related to their own teaching activities, including laboratory work tasks.

I translate the teacher's concept of *didactical thoughts* to reflections on the intended learning outcome and the design of the teaching/learning sequences; *what* should the students learn, *why* should they learn it, and *how* should they learn it? These reflections are - according to the teacher - substituted with habit and intuition, making sure the teacher and the students will survive the teaching/learning sequences, even though no one is able to explain what learning the task should provide and why.

[1] Year 10-12, see further information in appendix A
[2] The teacher did not teach physics the current year

This hypothesis that teachers substitute reflections with habit and intuition is the starting point for the following work. I perceive it as having a twofold aim: Firstly, as the developing of a tool for teacher reflections of the potential learning outcomes of the specific laboratory activities. The laboratory activities run in schools are to some extent dictated by the physics curriculum in the Gymnasium, but this does not necessarily provide teachers with didactical thoughts concerning the laboratory work. Secondly, the study provides a test of the changes (if any such is detectable), when the intended learning outcomes are explicitly stated, such that both teacher and students are aware of the rationales for doing the specific laboratory work activities.

Naturally the rationales and potential learning outcomes of laboratory work activities have been discussed as long as these types of tasks have been included in the school setting, but as will be reviewed later most of these studies relate to laboratory work in a general sense, including *all types* of laboratory work activities across *all school levels*, and within *all disciplines of science*, including physics, chemistry, biology, earth science, environmental science, etc. This study is instead seen as a linking of specific laboratory work activities to their potential learning outcomes in the setting of the physics classes in the Gymnasium, as well as a test of possible improvements when this link is clearly seen by the actors in the school lab environment.

Having very loosely described the research questions of this work, this chapter sets out to exemplify the understanding of the used concepts like *laboratory work* (labwork) and *potential/intented learning outcomes* (or purpose, goral rationale, etc.), which is used throughout the thesis. My personal motivation for doing this work is given, followed with a precise statement of the research questions and their limitations. The chapter ends with a reader's guide.

1.1 Setting the scene

Imagine a school laboratory in a physics class in the upper secondary school. Students are divided into small groups. Each group has - based on an elaborated laboratory guide - attached an air-filled syringe to a computer-interface pressure gauge. The piston of the syringe is relocated to change the volume read of the scale, and the corresponding pressure is noted down. After the taking in of data the students are expected to write a laboratory report including aim, theory, description of setup, measurements, results, sources of error and conclusion. What is the rationale for this activity? Based on literature, the rationale can be given as e.g.:

1. to learn how to operate a computer-interface pressure gauge?
2. to learn how to operate nature scientifically?

3. to learn how to describe observations?
4. to learn how to classify observations?
5. to learn manual skills?
6. to learn how to collect, handle and data?
7. to learn how to operate safely in a laboratory?
8. to learn how to estimate uncertainties and appropriateness?
9. to learn how to judge methods?
10. to learn how to generalize?
11. to learn how to make scientific hypotheses?
12. to learn how to design an experiment testing the hypotheses?
13. to learn how to perform the experiment in a systematic, reproducible and scientific sound way?
14. to gain problem solving competencies?
15. to learn how to compose a laboratory report?
16. to learn how the world of theory and models relates to the world of phenomena?
17. to learn about the methods of science?
18. to learn about the nature of science?
19. to learn how knowledge of the world is gained?
20. to evoke interest and gain motivation in relation to physics?
21. to fulfil the curriculum demands of laboratory activities?
22. to train for the upcoming experimental exam?
23. to learn about the equation of state, states of matter, the concepts of pressure and volume etc.?
24. to verify that the pressure of a gas is reciprocal to the volume?
25. to determine the value of the gas constant by use of Boyle's law?

To determine the value of the gas constant by use of Boyle's law would likely be the official aim of the labwork, as it is found in the laboratory guide (labguide). But if the intended learning outcome was truly just to determine the value of the gas constant, a faster and more precise way is to look it up in a database.

All the remaining rationales might be more or less rational reasons for placing such an activity in the school physics classroom. But they are sort of floating in the air, not necessarily being neither explicitly nor implicitly known or understood by the students. Is it then reasonable to expect the students to gain insight on all of these things?

In a 2004 review paper concerning research in labwork activities in science education, Hofstein and Lunetta write how the students lack understanding of the teacher's intended learning outcome of the specific labwork activity, and which rationales the students then hold for the task:

> Chang and Lederman (1994) and others (e.g. Wilkinson and Ward (1997)) have found that often students do not have clear ideas about the general or specific

> purposes for their work in science laboratory activities. Other studies have shown that students often perceive that the principal purpose for a laboratory investigation is either *following the instructions* or *getting the right answer*. They may perceive that manipulating equipment and measuring are goals but fail to perceive much more important conceptual or even procedural goals.
>
> (Hofstein and Lunetta (2004), p.38, original emphasis)

So apparently students often hold difficulties in relating the laboratory work activities to reasonable rationales, and therefore perceive the teacher's intended learning outcome to be to solve the task as planned. Hofstein and Lunetta continue by underlining the importance of both teachers and students to be explicitly aware of the purposes of the specific labwork activity for the goals to be reached:

> To guide teaching and learning, it is very important for both teachers and students to be explicit about the general and specific purposes of what they are doing in the classroom. [...] Since there is evidence that the goals of instruction are more likely to be achieved when students understand those goals, Wilkinson and Ward concluded that teachers should be much more attentive to helping students understand the general goals of the laboratory work. Since specific objectives are often different from one laboratory investigation to another, students should be helped to understand the purpose for each investigation in a prelab session and to review those purposes in postlab reporting and discussion.
>
> (Hofstein and Lunetta (2004), p. 38-39, original emphasis)

As they state, the possibility of reaching the intended learning outcomes of the specific activity increases with the students' understanding of them: so tell the students why they are doing what they are doing when working in the school laboratory, and then they will more often reach these goals.

So let us now imagine the teacher telling the students prior to the labwork activity that the purpose of the activity is to gain insight into the relation between the world of nature and phenomena and the world of theory and model. Would that help? My guess is it will not make it much more clear to the students, and they would continue thinking the purpose of the labwork is to get the right results or following the given instruction.

Let us instead investigate which kind of specific purposes - or with other words which specific potential learning outcomes - this particular labwork activity could meet. Let us view the labwork as an exemplary example of a learning activity for a general principle in physics. One possibility could be the concept of *variables identification*: to understand the idea of a variable and to identify the relevant variable to change (the independent variable), the relevant variable(s) to control, and the relevant variable to measure (the dependent variable).

In all laboratory work activities it is important to identify the variables, but in this specific laboratory work activity concerning the ideal gas law, the students need to choose the independent variable to vary among several parameters (the temperature, the volume and the amount of matter), and having chosen the volume as the independent variable and the pressure as the dependent variable the students needs to move back and forth between the mathematical statement of $y = a/x$ and the physical statement $p = nRT/V$. This is not a trivial task. In mathematics students are used to the formalism of $y = a/x$, where it is always the case that x is the independent variable, y is the dependent variable, and a is the constant. In the physical equation $pV = nRT$ it is not in the same way obvious to the students which variables serve the role of x, y and a[3]. Therefore this specific labwork activity serves as an exemplary example of a more general principle: namely variable identification.

So why is specific labwork activities not always correlated with such relevant learning outcomes? Why is it not made explicit that the labwork activity was designed and implemented for exactly this purpose?[4] The teacher in the introductory quotation has already given the answer. The school setting does not leave room for or demands of didactical thoughts of this kind. And the laboratory activity *can* run without it. When the students believe the purpose of the labwork activity is to get the job done in a reasonable manner, the situation makes sense to them. And the students are most often returning laboratory reports fulfilling all demands the teacher have set, and therefore it is easy to draw the conclusion that the students have learned what was intended with the activity.

Having the underlying premise that to some extent teachers and students are not explicitly aware of the purpose of the specific labwork activities, the thesis sets out to develop a set of relevant rationales for the most common labwork activities - and to test to which extent the explicitness of the purposes actually enhance the achievement of these goals.

This withhold an important choice in my work. Working with labwork activities, I could have chosen to pursue by developing one or several new teaching/learning modules for the physics school laboratory, implement them in a number of school classes, and testing their effectiveness on a number of parameters, that are found important. Instead I have chosen another road by examining the most common labwork activities and unfolding their potential learning outcomes. The reasons for doing this are multiple, but two underlying ideas are: (a) traditions are difficult to overturn and should therefore be investigated to see if they hold potentials before discarding them for something new which most likely will not be implemented easily, and (b) there *are* potentials in the often used labwork activities, else they would not be that common - some of the students *do* reach the potential learning outcomes that the task holds even though students and teacher are not fully aware of these.

[3] Also in physics each variable contains both a magnitude and a unit, where as in mathematics the variable only has a magnitude.

[4] These claims will be justified to a higher degree later both in literature review and in my data.

1.2 Personal motivation

I love to do physics. Physics was for me - since my interest aroused in the Gymnasium - nice, challenging and most importantly ordered - at least when disregarding the laboratory work.

I have during the last years of my Gymnasium and my time at university - where I was studying physics - experienced a great increase of personal interest in laboratory work. Initially working in laboratories were for me the least enjoyable part of studying physics. The laboratory was somewhat useless. Firstly since I sincerely trusted the results found in books to be taken with much larger care and precision than the student labs were ever able to. So why demand that I should repeat an experiment done thousands of times before? Secondly, because the results were often messy and imprecise; this was for me a large contrast to the beauty and orderliness of the theoretical physics.

During my graduate years at university I came to see myself as an experimentalist, loving to work in the research laboratory. I grasped to a more refined level how the theoretical physics was only one side to the coin, and how the world of theories and models had to play up against the world of phenomena and empirical data for the cause of developing the body of physical knowledge. This shift from disliking to loving the physics lab has fascinated me enough to wishing to investigate student laboratory work in the subject of physics.

Initially I wished to find a way to improve the teaching of laboratory work in physics; to find 'the solution' of the problems. I expected this to be rather easy, since I took the stand that almost all of my experiences in school laboratories were quite dreadful, leaving plenty of room for improvements. I almost expected any change would lead to gains in both the learning outcome and the affective domains. I was (and still is) very fond of the ideas of enquiry-based labwork, open-ended tasks, problem-based learning, etc. Therefore I was very enthusiastic, when I was invited into a physics class in the Gymnasium where an alternative labwork activity was to take place. To my large surprise the students experienced large problems and frustrations related to the shift between the fun of taking in not too well-considered data and the hardness of understanding how these data was to be transferred to some kind of conclusion. The students accused the teacher for not having laid out clearly enough the intentions for this project, and they also accused their peers for not having listened carefully enough to the teacher when explaining the task agenda (see section 4.1.3 for an elaboration).

During my next observation I came across another teacher; her way of teaching was by the first sight not that different from any other teaching styles I have experienced as a student (strongly guided). The largest difference between her way of teaching and what I was used to was her awareness of the intended learning outcomes of the labwork task in play (see section 4.2.1 for an elaboration).

I came to think that most teachers have a clear-cut plan for every part of the lesson; all teachers are having a thought-out idea of what the students should learn from every introduced activity. Several additional observation in Denmark and during my exchange visit overseas (Melbourne, Australia) I realized the naivety of this idea, which was also highlighted by the initial quote at page 9. I met teachers only being able to articulate purposes of labwork activities in very general terms and not finding it important or possible to point to where these purposes could be extracted from their teaching of the specific labwork in play. I saw teachers performing highly regarded teaching, but not articulating their intentions for the specific practical works when introducing them to students. I even met a teacher stating laboratory work was only a way to vary the lessons, like showing a movie. And I saw students being high-achieving students believing labwork activities were all about getting the right answer.

I find it important to facilitate teacher's development of own understanding of the possible purposes of the specific practical work. I also find it important to investigate if and how it makes a difference to the students, if the teacher indicate/show/explain his or her purpose of the experimental work. Questions like: *Do the students become more motivated? Do they learn more by knowing and understanding the teacher's purpose of the activity?* push forward. Is a well-designed laboratory module enough, even though the teacher and the students are not aware of the purpose?

Besides my interest in changing praxis of teaching in the school laboratories, this is also a personal quest for me. Prior to this PhD study I have spend close to no time at meta-issues of my beloved discipline of physics. Doing research in physics education research is a great opportunity to reflect upon what physics is, what criteria physics poses for trustworthiness and generalisability, and to which extent physics is objective. I know now I held a very naive understanding of the nature of physics, and it has also been a joy and challenge for me to develop my understanding of my scientific ground. My physics background has lead me to hold a certain perspective on truth and the creation of academic knowledge. This had to be re-negotiate, wherefore occasionally I have felt the rock under my feet to be shaking.

Doing research in physics education is very different from doing research in physics. I have struggled to teach myself to read literature free of equations, graphs and the familiar physical concepts. It has been surprisingly hard to understand what people mean when expressing themselves in writing concerning issues like teaching and learning. Many of the used concepts and terms are not well-defined, and those that are might not be used according to the definition after all. Also the cultural setting which the research takes place in, has a huge impact on the conclusions to be drawn. And none of these issues used to be a problem or concern in physics (then there were other concerns, but I leave that story behind).

But still I wish to underline the 'amazingness' of the journey, which I feel have enlightened me both in relation to my old field of physics and my new field of physics education research.

1.3 Research questions and their limitations

As the research questions have loosely been given in the first part of this chapter, this section sets out to formulate and unfold the research questions in a more precise sense.

This PhD thesis took off as an investigation of the current way of teaching and learning in the physics laboratory. Early observations lead to question the teachers' level of awareness of the potential learning outcomes of their labwork activities. These observations indicated various levels of awareness, as well as showing how difficult a task it is to become aware of the potential learning outcomes of specific labwork activities.

These reflections led to the research questions. The precise formulation is:

1. *Which potential learning outcomes do the laboratory work activities commonly used in physics in the Danish Gymnasium hold?*
2. *What is (if any) the impact on the students of a declaration of the teacher's intended learning outcomes of the specific labwork?*

The term *laboratory work* is used for school activities of students doing experiments or practical exercises with scientific apparatus in school laboratories. *Scientific apparatus* is here understood in a broad sense, including devices like microwave ovens, cell phones, digital video recorders and sun glasses, along with more traditional devises such as thermometers, rulers, springs, voltmeters, etc. Computer simulations and virtual laboratories are not perceived as laboratory work. *School laboratory* is also understood in a broadly. When the work includes measurements or observations in a setting within the school or the near surroundings, it is perceived as laboratory work. Field trips and visits to universities, research facilities, museums, companies and exhibitions are not included. Neither are teacher demonstrations nor problem-solving without observations or measurements (e.g. when the teacher hands over data from for students to handle) included.

1.3.1 First research question

The first question *Which potential learning outcomes do the laboratory work activities commonly used in physics in the Danish Gymnasium hold?* deals with how to relate the current laboratory work tradition in the Danish Gymnasium with the potential learning outcomes that laboratory work as a teaching-learning activity hold. This research question contains two preliminary sub-questions: *Which potential learning outcomes of laboratory work exist?* and *What is the current tradition of laboratory work in physics in the Danish Gymnasium?*

The first preliminary sub-question is *Which potential learning outcomes of laboratory work exist?* This question should be answered by an extensive literature study, both in national and international research literature and by an analysis of the regulation and curriculum of physics for the Danish Gymnasium. This work is thought of as a way of ordering the ongoing discussion of the labwork activities' rationale; categorizing the purposes in large headlines and investigating which sub-rationales are to be included in the general categories.

The second preliminary sub-question *What is the current tradition of laboratory work in physics in the Danish Gymnasium?* should be answered by developing a typical series of labwork activities for each of the three years of the Gymnasium. An investigation of the curriculum for physics in the Gymnasium will hint which core contents are on the line, and how much time is expected to be spend on laboratory work. This series should then be developed based on labwork activities collected from teachers from the Gymnasium around Denmark, from various teacher-run databases, from student-run databases, books, notes, etc. Asking this question is it implicitly expected that the tradition is rather strong and stable amongst teachers and classes in the entire Denmark. It is important that the development of the typical series of labwork activities does not include a large analytical framework, which could cause circular arguments in the sense that the traditional series of labwork activities should not be developed in such a way, that the activities are chosen based on their purposes, making the answer to the first research question (*Which potential learning outcomes do the laboratory work activities commonly used in physics in the Danish Gymnasium hold?*) self-evident - and thereby irrelevant. Since the Gymnasium underwent a reform in 2003 (implemented in 2005) effort has to be put into making sure the collected series of laboratory work activities is not a reminiscence of a tradition, which does no longer exist.

These two preliminary research questions lead on to the first research question *Which potential learning outcomes do the laboratory work activities commonly used in physics in the Danish Gymnasium hold?* Where the two preliminary sub-questions were related to investigating practices and literature with fairly un-critical lenses, as a description, cleaning up and drawing of general lines and tendencies, this question demands a more personal line of choices. Here I have to judge the different goals of labwork activities and finding those which I find most valuable for the context of the physics classes in the Danish Gymnasium. Having done that, I investigate each of the labwork activities in the series for their potential learning outcomes and then pair the chosen purposes with the found series of labwork activities, and thereby to some extent re-define the labwork activities in relation to the given potential learning outcomes. This should be seen as a scheme, a reflection tool for physics teachers, and not as a dictation of the purposes of the used laboratory work activities.

The first research question is seen as a way for describing purposes of laboratory work activities in a very direct way, anchoring the discussion on the ongoing tradition, making the discussion direct, concrete and tangible. This scheme is having its justification both among researchers in the field - as a development of a tool for discussion labwork activities in a different way; but even more as a tool for the teachers to develop their own teaching in laboratory work, based on their own teaching tradition.

1.3.2 Second research question

The second question is *What is (if any) the impact on the students of a declaration of the teacher's intended learning outcomes of the specific labwork?* This is a test of the arguments for answering the previous research question; is it worthwhile?

The second question is a critical investigation of the often un-argued hypothesis that making the goal of labwork activities explicit to the students will highly increase the possibility of reaching the goal. Is it possible to make such a conclusion, and under which terms can the question be answered?

For quite some time the question was formulated as *What is the impact of a declaration of the purposes of the laboratory work, measured on the realisation of the purposes?* This formulation was rejected for two reasons, depending on how to approach the problem:

One way to answer the question is to implement the same labwork to a large number of students with different declaration levels of the intended learning outcome. Having initially cleared the groups by use of pre-tests, the students could then after the labwork be tested in a pro-test (and possibly yet another one some time later), and thereby quantitatively investigate the impact of declaration levels. The answer to the question will then be based on the answers of the test.

Another way to answer the question is to thoroughly investigate a small number of cases, where the teachers do their own labwork activities in the way they usually do. The declaration level could then be determined for each case, where after the students' approach to the labwork was analyzed in relation to the declared purpose by the teacher.

As will also be discussed later (see chapter 3), the first way holds a number of potential problems in relation to determining what to ask for, and if such tests is even a reasonable and trustworthy way to investigate the realisation of the purposes. For the second way, pilot had shown how a number of teachers do not declare the intentions at all, wherefore it is important to judge the case based on measuring the realisation of the purposes, if none such is given.

The research question was then reformulated to the above, such that it can be investigated in relation to data extracted from a number of 'naturalistic' empirical studies of school laboratory activities including observations, video recordings, teacher- and student interviews, laboratory reports, etc. It compares the students' way of engaging in, talking about and reporting on the labwork activity, when being taught by teachers with different views and traditions on reflecting on and articulation of purposes of laboratory work activities. This work is followed up by an 'experimental' study of teachers running two laboratory activities with the same students and within the same subject but with very different levels of explicitness of the purposes of the laboratory work activities, investigating if on such a small time scale any differences occur; does it have any detectable impact?

Many authors put it as self-evident that students will be more motivated and gaining more knowledge when understanding the teacher's intentions for a given experimental activity, e.g. Woolnough and Allsop (1985); Nott and Wellington (1996); Wellington (1998b); Millar (1998); Hofstein and Lunetta (2004). Still it is rarely seen in schools that teachers spend the time explaining to the students, why they should perform a given activity. Several reasons for this can be listed: First the teacher might not himself be aware of the purpose of the activity. Second the teacher might not be able to articulate the purpose. Third the teacher might have a reason for not explaining the purpose to the students (it might ruin the surprise). Finally the teacher might have experienced that the students are not more motivated for doing the work, or they are not learning any more when the are explained the purpose, than when they are not.

The second question is in a sense a survey of the importance of asking the first question. If the study of the second research question returns positive correlations between declaration levels and impacts on the students, the scheme has to some extent proven its worth within the methodology used for detection. If the survey on the other hand returns negative or non-detectable correlations, the conclusion does not necessarily mean the reflections embedded in the answering of the first research question is of no value, but could be interpreted as a result of the impossibility to detect such differences with the methodological tools used. In relation to the discussion of the variable identification in the previous section, this exactly hit the nail on the head; this kind of survey has poor control of the variables in play, even though all effort has been put into keeping most of them the same. But it does not mean nothing important can be said or deduced, it just has to be viewed in a critical light.

In that way the second research question could be very broadly formulated: Does it make a difference on the students' learning, if they are explicitly given the teachers' intentions of the teaching/learning task. The answering of the broad question is tried answered in the context of Gymnasium physics. I do not claim that the results can be directly transferred to all other disciplines or school levels, but I expect the results to be more general than the context in which they are investigated.

1.3.3 Limitations

PhD studies within this field have a tendency to become very large and very broad. We are all driven by the hope to change everything to the better, and therefore it is simply not enough to fiddle around with a small corner of the very large field of physics education research. Having narrowed the study down to only concerning physics laboratory work in the Danish Gymnasium, still the field is large, and many research questions, agendas, frameworks and methodologies can be chosen, and a further limitation has to be done.

This thesis does not try to clarify why we should teach physics in the Gymnasium - or even larger why the public should have access to an understanding of physics. Physics *is* a part of the Danish Gymnasium, and that is taken as a premise. Instead my research questions centre on the role of labwork activities in the physics education, and the aim of practical work in physics education.

My supervisor Jens Højgaard Jensen divides all didactic questions in physics into two parts; *inner issues* and *outer issues.* Inner issues deal with the discipline itself, in this case physics. Outer issues deals with the position of the discipline in a broader perspective, both horizontal; comparing it with other disciplines on the same level, and vertical; comparing the discipline and the bridging of the course between different levels, e.g. primary school to Gymnasium, or Gymnasium to tertiary level.

A typical example of a report operating on the inner issues is the KOM-report[5] (Niss and Jensen 2002), where the nature of mathematics is discussed independent of the level or position of the discipline. In other words: mathematics for itself. Inner questions within physics are of the like: How do we teach physics? Which specific physics competencies and physics knowledge should the students gain?

Examples of outer issues are school and university politics, where the role, function and even the extension of a discipline are discussed in the broader per-

[5] The Danish project concerning competencies and mathematics

spective. Outer questions are questions like: Why should students learn physics? What is the role of physics in the Gymnasium? Which general competencies do students gain in the most prominent way from their physics classes?

This project is an 'inner issue' project. This project clarifies and discusses what laboratory work can do for physics generally within the Gymnasium, and not what it can do for physics at tertiary level, what it can do for other disciplines, or the general goals of the Gymnasium. In that sense, I do not go into the discussion of the effect of general education of laboratory work in a broad sense, but only the effect of general education it gives to the discipline of physics.

First, I need to clarify that I acknowledge the discussion of the role of physics education to fulfil the goals set out for the Danish Gymnasium, which according to the regulation of 2003/2005 is two-fold: preparing the students for further studies and general educating the students. But this dissertation does not set out to discuss this, and I leave this discussion to others.

Second, this could be a discussion of the role of labwork activities as a means to teach students the issues physics education aims for. To discuss this question, the aims of the physics education should be articulated and discussed, and labwork activities should be critically analyzed to see if other teaching processes could be more efficient to meet the aims. This discussion is important, but is not the concern of this study.

This work takes its start in the fact that practical work is a part of the current teaching of physics in Gymnasium, and then tries to clarify what potentials the labwork activities hold?

1.4 Reader's guide

In this section it is discussed which readers might gain from this study, and a reader's guide is presented, describing the structure of the following chapters, along with a short description of the transcript codes used for the shown transcript data.

1.4.1 Which readers would benefit from this work?

This thesis has swelled in size, and therefore different readers could benefit from reading different parts. But generally I perceive potential readers to be researchers in the field of physics and science education, curriculum makers, as well as teachers. The results are developed with the Danish Gymnasium in mind, but as discussed in the very end a lot of results could be generalized to universities, upper secondary school systems, primary and lower elementary schools, both nationally and internationally, and some of the results could be generalized to other disciplines, primarily chemistry and general science courses.

1.4.2 Thesis structure

The thesis is divided into five parts, each dealing with different issues relevant to the study.

Part I 'Introduction to the study' has two chapters. The first chapter 'Impetus and focus' is this one, containing a setting of the scene which is understood as a first glimpse of the research questions, a personal motivation for the choice of this study, as well as a presentation of the two research questions.

Chapter 2 'Placing the study in the scientific landscape' deals with how to understand this study and these research questions in a larger picture. This is investigated in two ways. First by viewing the field of physics education research and its different research paradigms, and discussing why this study then has to be investigated within a specific way of perceiving physics education research (and its related fields of science education research and mathematics education research). The second way is by providing the reader with a short literature review of research done concerning laboratory work in physics or science education research, and by identifying recent trends.

Since this study has developed as an iterative process between reflections upon the relevant literature and empirical investigations at Gymnasiums the readers should early on be acquainted with the empirical cases upon which this study has emerged as well as being the basis for answering the research questions. Therefore already part II called 'Introduction to the empirical data' deals with the empirical case studies. The part contains two chapters. The first chapter 3 'Methodological considerations' discusses in which ways the research questions can be answered. That is considerations of to which extent the research questions can be answered, and which methodologies and methods can be used to answer the questions in the best possible way. The methodological choices are discussed in relation to the possible validity and reliability.

The second chapter of this part - chapter 4 'Empirical investigations of teachers' labwork purposes' - presents shortly the pilots upon which the research questions and research designs are based, and is then followed by a description of the empirical cases serving to answer especially the second research question: "*What is (if any) the impact on the students of a declaration of the teacher's intended learning outcomes of the specific labwork?*". To do so the declaration level of the teacher's intended learning outcomes needs to be clarified, and this is looked into by investigating interviews, labguides and the teachers' introductions of their labwork activities to the students. On the basis of these investigations some preliminary conclusions can be made, not directly answering the research questions.

Part III named 'Linking labwork activities and their potential learning outcomes' deals with the first research question: "*Which potential learning outcomes do the laboratory work activities commonly used in physics in the Danish Gymnasium hold?*" To answer this question first an immense literature review is done to investigate which potential learning outcomes there exist for laboratory work activities (found in chapter 5 called 'Purposes of practical work'). The purposes of labwork activities are looked into by a number of sources, such as curricula studies (up through history), studies of teachers' as well as physics education researchers' perceptions of the issue. On this basis a sixfold categorization of purposes is developed and further investigated in order to extract a valid (normative) understanding of each of the six categories.

The second chapter of this part - chapter 6 named 'Linking practical works and purposes' - investigate how the six purpose categories can be linked to different labwork activities. First earlier work on relating different labwork purposes with different labwork types are reviewed, and on this basis six labwork types are described and then linked to the six labwork purposes. This framework of linking labwork types to labwork purposes can be seen as a way to focus the design of a labwork activity to match it to the intended learning outcomes of the task. To further investigate the first research question a typical series of specific labwork activities used in each of the three years physics classes in the Danish Gymnasium is developed, and each of these are categorized within the described framework. On this basis each of the specific labwork activities of the typical series are analyzed in order to shed light on their specific potential learning outcomes.

Part IV again deals with the answering of the second research question, now focusing on the students and the impact the different declaration levels have on their work with specific labwork activities. The first chapter of this part - chapter 7 called 'Reflections on the impacts of declaring intended learning outcomes' - investigates literature emphasizing declarations of intended learning outcomes. The concept of metacognition - and with that the research tradition of conceptual change and the epistemology and learning theory of constructivism - is recognized as holding the same grounds, wherefore this study service metacognition by providing research results in its favour in the same way as metacognition provides concept clarifications, research methods and methodologies to this study.

The second chapter of this part - chapter 8 named 'Empirical investigations of the impacts of declaring intended learning outcomes' - deals with the empirical answer to the second research question, where the impact of different declaration levels on the students are analyzed in a number of ways to provide method triangulation in order to make the results stand stronger. Video recordings of the students' engagements with the labwork activity are analyzed both quantitatively and qualitatively in order to gain insight to the impact of different declaration levels. This is compared to results based on student interviews as well as analysis of the lab reports. Summing up all of these results, clear indications of a significant impact of a high level of declaration.

In the final part V of chapter 9 the study is summarized, and its trustworthiness, generality and importance are investigated. This is followed by discussions of the use of the study in research as well as in practise are discussed, along with an outlook of which type of further studies could be relevant to pursue.

1.4.3 Transcription notes

Transcripts from interviews, teachers' introductions and students' labwork activities are used to answer the research questions, and some signs and codes are used to describe these. All transcripts are given line numbers, and these always refers to the line numbers of the transcript report. Else some other symbols are used to include additional information relevant for the reader not having access to the video or audio:

Code	*Description*
[...]	A part of the transcript has been left out.
[**Comment**]	Comments to the transcript included to explain relevant issues, e.g. tone of voice, body language, only addressed to a specific person, said while writing an equation on a paper, pointing towards something in the labguide.
[**Bad audio**]	When it has not been possible to extract what is said, it is given this comment, sometimes followed by the best guess.
Blah blah ... blah	'...' indicates a pause.
Blah blah ...	'...' indicates the talk is interrupted by another talker.

2 Placing the study in the scientific landscape

After having introduced the research questions of this study in section 1.3, the reader is entitled to know how the answering of these questions can be placed in the scientific landscape.

I recognize (at least) two ways of doing this. The first is through a *review of existing literature* within the relevant field - for this case labwork in physics. The other way is through *reviewing the various research paradigms existing in the field* and placing this piece of research in that landscape of research traditions. In the first case of the field-specific literature review, it will provide an overview of the research done in the field, new trends and everlasting discussions (section 2.2). The latter case of the paradigm review will provide the reader with an overview of the various ways of perceiving what 'good research' is and e.g. what role theory and empirical data hold within the various paradigms (section 2.1).

The two sections are asymmetric in the sense that the literature review in section 2.2 is only meant to be succinct, since the discussion of arguments for labwork (both on a research basis and as interpreted by the curricula and in the school setting) is left for part III. The section concerning the research traditions is not unfolded later in the thesis, and should therefore be read as a complete whole.

Due to the special character of this chapter, a reader who is primarily interested in the research results of this study should have close to no problems skipping this chapter and go straight on to the following part. But I hope the chapter will be of value both for those that are unfamiliar with either the research area of labwork in school physics or the multi-paradigmatic nature of the field of physics education research (or for those belonging to other research paradigms than the one I belong to and therefore am not agreeing with my research choices).

2.1 Research paradigms in physics education research

Physics education research (PER) is a fairly new and largely growing field - in the US they claim to have 'invented' it only three decades ago (McDermott and Redish 1999), but on the Continent 'we' have been working with it significantly longer under the German terms of 'Physik Didaktik' in German or 'didactique de la physique' in French[1].

Physics education research is taking in frameworks, ideas, reflections, methods for data collect and interpretation, etc. from the humanities, the social sciences, *and* the natural sciences. In this area of tension, physics education research has to find its own nature. Since I expect the reader, as myself, to have a stronger background in the natural sciences, I feel the need to clarify which similarities and difference the nature of the arts hold to the nature of the natural sciences.

As stated by Kjørup (1996), for many years the natural sciences were the role model of the arts. By quoting John Stuart Mill, Kjørup makes this point in concern with the humanities: "The backward state of the moral sciences can only be remedies by applying to them the methods of physical science, duly extended and generalised." (Mill (1872), opening line)

And Kjørup outlines how this view lasted long after the end of the 19th century:

> At least until the late 1960s it remained a common view that the humanities were only halfway there at becoming a real science, and that this was caused by the fact that the humanities had not taken in the methods of the natural sciences as their role model; or more precise: that the humanities did not use 'the methods of natural science'. According to this line of thoughts there only exists one type of scientific methods, namely those which with great success has been used in the natural sciences. [...] Now the claim is still more rarely made, first and foremost because the positivistic view of science, which it usually connects to - and which Mill was one of the founders of - more or less is abandoned.
>
> (Kjørup (1996), p. 85-86, own translation)

As Kjørup state, the humanities are now rarely aiming for the methods of the natural sciences. Maybe due to the youth of the field of research in physics education, but more likely to the fact that most researchers in physics education have a strong background in physics, this idea of mirroring the methods of the natural sciences on the research field of physics education are quite common, as expressed in e.g. the bibliographic paper by McDermott and Redish (1999):

> In the selection of references, preference has been given to papers in which the approach and the rules of evidence are close to those traditional in the physics community. However, experiments in physics education differ in a number of respects from the idealization of a traditional physics experiment. Among the

[1] Originally the English term 'didactics' is used for a lecturing and sermonizing way of teaching. In continental languages, including Danish, Didaktik/Didactique means the study or art of teaching.

> differences are: (1) a limited ability to identify and control all the variables, (2) the necessity of using a strongly interacting probe, and (3) the degree of quantification that is appropriate.
>
> (McDermott and Redish (1999), p. 757)

McDermott and Redish do not see this as a serious problem; it is a mere question of applying certain methods and considerations to the research done.

Using the research field of physics as an ideal for research in physics education raises - I claim - large problems in relations to the pillars upon physics stand: objectivity, reproducibility, generalisability, etc. How can one work objectively when interpreting the behaviour of people in the same sense as when working with electrons? How can an experiment with students be reproduced in the same way as with molecules? How can one talk about generality among the behaviour of people in the same sense as when talking about photons? McDermott and Redish would pose this is possible by a substantial effort of controlling all variables, by being aware of the interaction of the measuring probe and by use of quantitative methods with a significant number of participants.

As is probably obvious I find this view on physics education research very simplistic and to some extent old-fashioned. Turning towards the somewhat more well-established field of mathematics education research, such discussions of closely mirroring education research on the research in natural sciences seems to have been buried back in the 1970s (though with a revival in the US within the last 10 years (Lester 2005, p. 457)):

> [M]any thoughtful people are critical of the quality of research in mathematics education. They look at tables of statistical data and they say "So what!" They feel that vital questions go unanswered while means, standard deviations, and t-tests pile up.
>
> (Scandura (1967), p. iii, quoted in Lester (2005), p. 457)

Wellington and Szczerbinski (2007) discuss the social sciences as opposed to the science of physics in the following way:

> Social research rarely goes according to plan - it can be messy, frustrating and unpredictable [. . .] These are the differences between social research, which deals with humans, their society and culture and their organizations, and research in physics, which deal with inanimate, idealized entities such as point masses, rigid bodies and frictionless surfaces.
>
> (Wellington and Szczerbinski (2007), p. 3)

Though I find use of Wellington and Szczerbinski when discussing social sciences, I find their understanding of physics quite one-sided. Very rarely you get your hand on real objects in the physics laboratory, which act like point masses or frictionless surfaces. The science of physics can also be messy, frustrating and unpredictable. I find the difference lie in the understanding of the concept of *truth*. I used to, when working in the physics laboratory, to believe we chased after the general and everlasting truth of (a very small part of) nature, and that the chase was a reasonable activity. I am not so sure I chase for the general and everlasting *truth* when working with physics education research, since these concepts simply do not make sense in this setting. I, though, have also started doubting the pure truthfulness of the work done in my physics laboratory, where things were also messy, un-reproducible, and imprecise and to some extent a question of interpretation based on our opinions and unclear assumptions. Still I find there is a large gab between these two disciplines. Still I find it easier to convince both myself and my peers to believe in conclusions I draw based on the data collected in the physics laboratory than the conclusions I draw based on observations and interviews in physics classrooms.

But if not *only* wanting to mirror the methods and stands of the natural sciences on physics education research, then other values have to be given for judgements and justifications of the 'goodness' of research studies. I have found it valuable to take as a starting point the book by Wellington and Szczerbinski (2007). I acknowledge this book over the plethora of books of social sciences, since the first author is also an editor of several publications concerning labwork in science education, e.g. Wellington (1989a 1994b 1998a).

Wellington and Szczerbinski define the values upon which social science stands:

"...social research is inquiry that is critical, self-critical and systematic, that is, rational. But we would also add the word empirical." (Wellington and Szczerbinski (2007), p. 13)

The term *critical* refers to the researcher closely scrutinizing the data collected in the research. The term *self-critical* refers to the researcher being critical to their own analysis and interpretation and conclusions. *Systematic* they explain by quoting Stenhouse's definition of social science "Systematic enquiry made public." *Empirical* refers not necessarily to all research in social science being empirical, but that it takes its basis on empirical data: "...grounded in and constrained by empirical data." (Wellington and Szczerbinski (2007), p. 13)

I find this way of understanding social sciences and its methods constructive, since it emphasizes the criticality and self-criticality as the basis for good research within this field; it is not sole about explaining but equally much about *justifying*. I hope that this dissertation will prove itself critical and self-critical, besides systematic, which is a quality stamp for research in physics as well as physics education research.

2.1.1 Research traditions in PER

Maybe due to the short history of physics education research - or maybe due to the different nature of physics education research compared to the nature of research in physics - PER is a multi-paradigmatic research discipline. This causes a variety of understandings of the aim and role of research, including theory and empirical data. Not acknowledging the research paradigm under which a particular research study is done might cause misinterpretations and misunderstandings.

I have while working with physics education research recognized at least three types of research paradigms: the Anglo-American curriculum tradition, the German Didaktik tradition, and the French didactique tradition. In Denmark studies of education research are traditionally being familiarized with the German Didaktik tradition, but with the change of the academic language from German and Nordic to primarily English the Anglophone countries have had an increasing impact on their research in physics education research in Denmark. This three-fold split are recognized by others as well, e.g. Pepin (1999); Hudson and Schneuwly (2007).

Very simplistically, the three traditions can be described in the following way:

The *German Didaktik tradition* deals with development of reflections on *why* and *what* to teach to a higher extent than *how* to teach. Theories are used to initiate research question or to develop theories, but the purpose of research is not to justify theories. The research justification methods are primarily based on qualitative, naturalistic empirical data, but also theoretical considerations play a significant role (Westbury 2000).

The *Anglo-American curriculum tradition* deals with questions of ‘what works’: the purpose of research is to develop teaching-learning modules which increase the learning outcome. The research justifications are based on quantitative methods more or less modelled on the justification methods of physics itself, and theory seems not to play a huge role. The researchers in the Anglo-American paradigm place emphasis on their own experience as physics teachers, and let their research take of from this (Westbury 2000). For a clear-cut example, see the McDermott and Redish (1999)-quote at page 27.

The *French didactique tradition* deals with the development and verification of theories on teaching and learning of the content in play. The research tradition closely relates the subject to be taught (e.g. mathematics or physics) to the developed ideas of teaching and learning (Caillot 2007). Theories can lead to the development of teaching-learning modules, but the important role of research is to gain further understanding of the processes of learning. The research justification methods can be based on pure theoretical arguments, but will most often be investigated in more or less clinical experiments, where the developed theories are investigated on the basis of the theory itself.

In somewhat the same way Hudson and Schneuwly (2007) and Pepin (1999) describe the differences between the German Didaktik tradition, the Anglo-American curriculum tradition and the French didactique tradition:

> In the German context, *Didaktik*, in its different forms, can be described as systematic reflection about how to organise teaching in a way that brings about the

> individual growth of the student. This means that subject matters can open up different educative meanings for learners; and thus that teaching and learning follow different paths. Didaktik as presented is very different from a curriculum perspective where subject matter and meaning have to be close and also from the French tradition of *transposition didactique*, which is interested in differences between meaning and subject matter in order to enable the learning of the appropriate meanings of such matter.
>
> (Hudson and Schneuwly (2007), pp. 106-107, original emphasis)

and

> ...by looking at the models of teaching and learning in England and France, it seems that the Anglo/American research has been more empirically based than the French. The theoretical conclusions drawn from the Anglo/American research appeared to have emerged straight out of the empirical data. This belief in empiricism, research and theoretical conclusions on the 'here and now' (together with the belief in individualism) did not appear to allow researchers in England to develop a construct such as that of didactics. In French didactical research it seems as if there has been another layer of abstraction, in order to organise the thinking (for example, constructs such as *transposition didactique*), although didactical construct are informed by empirical research.
>
> (Pepin (1999), p. 61, original emphasis)

Naturally each paradigm is highly intertwined with the teaching philosophy of the geographical area where it is practised.

A comparison of the Anglo-American curriculum tradition and the German Didaktik tradition of educational research is done by Westbury (2000) - an American educational researcher, who is working on investigating how the Didaktik tradition can be used to develop the American philosophy of teaching and learning.

He describes how in the Anglo-American countries the teaching organization is build around a curriculum board in charge of developing templates and manuals for guiding the everyday school work. Therefore the responsibility amongst the teachers is 'only' to fulfil their duty of teaching the students what the curriculum and the board manuals state. Teachers can at all times be tested on their teaching abilities by assessing their students on national tests to see how well they do compared to a national average (Westbury 2000, p. 17). This leads research in this field to address and prescribe for problems involved in developing and implementing the curricula.

In the continental Didaktik tradition instead, the teachers do not receive manuals for their teaching from committees at a higher level. The curriculum gives the guidelines for the subjects to be taught, but the teacher has the professional autonomy to choose how to teach the subjects. The curriculum becomes educative as it is interpreted and performed by the teacher. In this tradition the concept of general education[2] becomes an important layer to the teacher's

[2] General education is used as the English term for 'almendannelse' (Danish) or 'Bildung'

choice (Westbury 2000, p. 17). The role of researchers in the field hence changes and research focuses on providing "…teachers with ways of considering the essentials what, how, and why questions around *their* teaching of *their* students in *their* classrooms." (Westbury (2000), p. 17, original emphasis)

The differences between the Anglo-American curriculum tradition and the continental Didaktik tradition are summarized in table 2.1.

Table 2.1 Comparison of the Anglo-American curricula tradition and the continental Didaktik tradition (Westbury (2000, p. 18), taken from Hopmann and Riquarts (1995).)

Level	*Curriculum*	*Didaktik*
Lesson Planning		
Core question:	How?	What and why?
Content as:	Object	Example
Aims as:	Tasks	Goal (direction)
Lesson plan as:	Course action	Frames of reference
Teaching as:	Enactment	Licensed
Research		
Focus:	Individual teacher, teacher thinking (interpretative)	Art of teaching, Didaktik analysis (hermeneutic)
Assessment of:	Student achievement	Professional
Successful teaching:	(Scores & standing)	Appropriateness, reflection
Theory		
Function:	Preparation	Initiation
Sequence:	Subject matter comes first	Bildung comes first

Even though these traditions from this table seem very far apart, according to Klafki (1995) the two traditions are concerned with the same set of issues (Westbury 2000, p. 16):

- the teaching and learning goals;
- the topics and contents that follow;
- the organizational forms and the teaching and learning methods and procedures;
- the teaching and learning media;

(German). The concept has close links to terms like general literacy and scientific literacy. Further discussions can be found in Petersen (2009).

- the prerequisites, the disturbing factors and the unintentional auxiliary effects; and the ways in which learning results and forms can be controlled and evaluated

Even though the two cultures address similar issues, there are fundamental differences in the way they pose and seek to answer questions concerning these topics (Westbury et al. 2000, p. 16).

2.1.2 Frameworks in PER

It is possible to find the three-fold division of the research paradigms described above in the discussion of *frameworks*, which is strongly related to the concept of research traditions/research paradigms. In line with Lester (2005) good research in physics/mathematics education should have a well-established framework or set of frameworks - whether these are theoretical, practical or conceptual (these terms will be discussed below). He states that good research uses the frameworks initially to pinpoint what kind of research questions is to be asked within the framework. This leads on to letting the framework set the scene for how the questions can be investigated theoretical and practical and which kind of answers the framework can provide.

Lester (2005) uses the concept of framework as a set of ideas, principles, agreements, or rules that provides the basis or the outline for something that is more fully developed at a later stage. He also uses the metaphor of a scaffold, which is a basic structure of ideas that serve as the basis for a phenomenon that is to be investigated.

Quoting Eisenhart (1991), Lester puts forward three types of research frameworks: *theoretical*, *practical* and *conceptual*.

A theoretical framework implies how he perceives theory as a specific kind of framework. Taking the stand of a theoretical framework, the research questions will be phrased or rephrased in terms of the chosen theory. The role of the research study done is then to support, extend or modify the chosen theory. Lester lists a number of benefits a researcher might gain from admittance to a specific theory, such as being granted the opportunity for following systematic research programs and sharing ones research with a closed set of peers having the same theoretical framework.

But, as Lester states, these benefits are overshadowed by a number of problems associated with the use of such a theoretical framework: (1) having chosen a theoretical framework, the researcher would most likely (more or less consciously) only see evidence in the data for supporting the theory. (2) In order for the data to serve the theory the local contexts can not be taken into account. (3) Having chosen a theory to serve the data makes it difficult to implement research findings to practice, and makes it difficult to explain results to practitioners. (3) Having chosen a specific theoretical framework makes triangulation[3] impossible.

Obviously, a theoretical framework is related to the French didactique tradition, which places emphasis on a theory, which is to be verified, tested and implemented in related contexts as it was originally developed from.

A practical framework is informed by the practice knowledge of those involved in the field such as teachers. This framework is not supported by any formal theory. It has the obvious advantage that the posed research is relevant for the involved practitioners.

Opposite it has the disadvantage that the level of generalisation is often very poor, and the insiders are rather bad at detecting norms and practices, since these are taken for granted: "...all too often insiders can't see the forest for the trees." (Lester (2005), p. 459)

The Anglo-American research tradition which places emphasis on the researcher's experience as teacher and emphasizes the 'what works' aim of research often uses practical frameworks.

A conceptual framework "...is an argument that the concepts chosen for investigation, and any anticipated relationships among them, will be appropriate and useful given the research problem under investigation." (Lester (2005), p. 460) A conceptual framework should then be understood as a scaffold for justification of the choices of the used theories, previous research literature, concepts etc.; the arguments for the relevance of the made choices. Due to the nature of the conceptual frameworks based on justification the chosen concepts and their relations must be defined and demonstrated within the contexts for proving its validity.

Finally, the German Didaktik tradition emphasizes the use of conceptual framework in using theories as an initiation, and aiming research on organizations and questions of why and what.

It is obvious that Lester find conceptual frameworks as the best choice for developing interesting and generalizable results:

> I propose that we view the conceptual frameworks we adopt for our research as sources of ideas that we can appropriate and modify for our purposes as mathematics educators. This process is quite similar to the thinking process characterized by the French word *bricolage* [...] A *bricoleur* is a handyman who uses whatever tools are available to come up with solutions to everyday problems. In like manner, we should appropriate whatever theories and perspectives are available in our pursuit of answers to our research questions.
>
> (Lester (2005), p. 460, original emphasis)

[3] Theoretical triangulation: alternative or competing theories are used in any one situation (Wellington and Szczerbinski 2007, p. 35)

When choosing a framework, one always has to ask whether this work could have been done without the use or scaffold of the chosen framework. If the answer is 'no'; then leave it behind.

Research tradition, framework and this study

I find my research questions and my stand on research provide me with the need of running with a conceptual framework in the words of Lester. Not only because he argues why this is the better way, but because my work does not fit into the theoretical framework, where I pursue a validation of a specific theory in the context of physics labwork activities in the Danish Gymnasium classes. Neither does my work spring from a practical framework where I based on teacher experiences develop e.g. a teaching/learning module for enhancing learning outcomes. Instead I look around for theories, models, data collection methods, analysis methods etc. for investigating and justifying my claims and hypothesis.

So why did I need to clarify my stand on research paradigms and frameworks? It is not uncommon within the field of physics education research to be demanded an articulation of the theoretical framework upon which your research is based (it has happened to me several times). This question has continuously puzzled me, since I did not find my research was based (understood as taken off from) a specific theory or set of theories, and I did not understand the need for it to be so. I expect that the question-posers perceive true research in the field to be based on a theoretical framework such as explained above, and therefore Lester have given me great comfort into feeling 'allowed' to pursue the work without having chosen a theory, but instead finding my work to be developing on a conceptual framework, pulling down tools and concepts from the shelves when in need. On the other hand, I have also often been asked to 'prove' my points in a quantitative way through e.g. tests, exam scores or questionnaire results. Again Lester (2005) has given me comfort in understanding how these people operate with a practical framework view of physics education research, where the question is concerning what works and a proof of it.

Left is just to explain why I call what I do 'physics education research' and not Didaktik of physics. The answer should only be seen as based on my choice on writing this thesis in English. Had I written it in Danish the used wording would obviously have been 'Fysikkens didaktik'.

2.1.3 The PER community

Physics education research as a community sees itself as a subgroup of science education research, and most researchers within PER publish in journals of science education and participate in conferences of science education. Some less profound relations exist to mathematics education research, which based on its longer history and larger number of researchers are more able to close around itself.

Physics education research borrows theories and methods from a long list of external research fields, such as philosophy, history, psychology, pedagogy, education (both general and discipline specific), anthropology, neuroscience, linguistics, etc., but naturally also from the research field of physics itself.

The following is not meant to review acknowledged publications within the field or to give an overview of the current trends and themes. Instead it consists of reflections of what research within physics education is. When is research of a high quality? What does it aim for? What is - and what is the role of theories, empirical data, and methods and methodologies?

2.1.4 What does PER aim for?

In line with the previous stated ideas about the ideal physics education research as modelled on research in physics (McDermott and Redish 1999), one of the authors, continues by give the aims of PER by:

> As educators, we want to understand how teaching and learning works in order to be able to teach our students more effectively. As scientists, we would like to do this using a scientific approach that combines observation, analysis, and synthesis like the one that has been so effective in helping us make sense of the physical world. Such a synthesis helps transform a collection of independent "facts" into a coherent science, capable of evaluating, refining, and making sense of our accumulated experimental data.
>
> (Redish (2004), p. 1, original quotation marks)

Though not agreeing with the views posed by Redish according to the methods and nature of physics education research's relations to research of physics, he still outlines the main aims of physics education research: *understanding* and *improving* the teaching and learning of physics.

These aims can be viewed in a number of different ways. Also the weight put on the understanding versus the improving differs.

Classically education research works with the questions of 'why?', 'what? and 'how?' (Sjøberg 2005, p. 36). *Why* should we teach the subject? *What* parts of the subject should we teach? *How* should we teach it to gain most learning? All of these questions should be unfolded, since each of them give rise to additional questions: 'why' depends upon 'says who?', 'what' depends of 'for whom?', and 'how?' depends upon 'in what circumstances?' (Inspired by Ogborn in (Jones and Lewis 1978, p. 3)).

Dolin unfolds these questions in the introductory article of the first volume of the Danish journal of mathematics and science education MONA (Dolin 2005), relating the why's, what's and how's to the macro-level (ministry, researchers, interest groups, etc.), the meso-level (schools, discipline specific groups of teachers, individual teachers) and the micro-level (students).

The questions of 'why?' are primarily posed at the macro-level containing education politicians, curricula makers, teacher educators, etc. Here are the intentions of the school discipline outlined and defined. The 'why?'-questions unfold to: what is the purpose of school physics in relation to the general aims of the educational level?; how much time should physics take up compared to other disciplines on the specific educational level?; which connections should physics share with other disciplines?; how is physics anchored to the institution?; which relations should school physics have to the research field of physics?; what role should it play in the teacher education; what should its role as a facilitator of general competencies be?; what should the relation of the discipline of physics be between other educational levels?; why teach physics, when only very few become physicists?; do the goals of the teacher coincide with the goals of the students?; etc.

The 'what' and the 'how' questions both relate to the meso level of the institution and the teacher, and the micro level of the students. The meso level deals with the implementations of the intentions expressed at the macro level, and the micro level deals with the realisations of the intentions and implementations expressed at the macro and meso level.

On the meso level the questions are of the type: What is physics' unique contribution? How is knowledge created in physics compared to other disciplines? What is the status of physical knowledge in relation to other disciplines? What is historically the role of physics? Etc. But also a problematizing of the role of school as an institution and a room for learning could be discussed at the meso level, where answers could be turning to informal learning environments.

Finally on the micro level Dolin identifies three major problems: what is the distinctive character of physics and how could and should it pervade the teaching and learning?; how can the interests and needs of the students be brought into agreement with physics?; and how should general theories of learning be adjusted to the content of physics education to focus on the special issues occurring?

Having discussed the aims of PER seen from the view of researchers (and practitioners) in the field it is worth noticing how these are not always overlapping with the outside political, societal and bureaucratic aims. The current problems of science education, such as recruiting students to tertiary level and retaining them, weak student motivation, gender issues, poor results in international tests etc., have according to Dolin (2005) lead to an increased political will to support science education research, explicitly or implicitly expecting an increased amount of research will solve the named problems - or at least showing off the political will to do so. This philosophy of the research might raise conflicts in relation to the aims from the research society underpinning the need of *understanding* - as well as *improving*.

This is discussed by Lester (2005). He identify a movement in the US, which

I also recognize in Europe (just see the large effect of the PISA results) towards dealing with 'what works' in education research; in other words to realize what kind of teaching strategies or procedures that serve the best results of student learning (or at least on students' assessment scores) proven by quantitative testing. This tendency became very clear during my participation of the AAPT[4] winter conference in 2009; see a description and critical analysis in Johannsen and Jacobsen (2009b).

Having discussed the aim of physics education research, I now turn towards the tools for reaching these aims. I here start with the concepts of theory, and in the following subsection I will discuss empirical data through the concepts of method and methodology.

2.1.5 Theory

Theory is a problematic term which is not easily defined. In the words of Wellington and Szczerbinski (2007)

> The role of theory in social research, just like the physical sciences, is to help us to understand events and to see them in a new or a different way. A theory may be a metaphor, a model or a framework for understanding or making sense of social events.
>
> (Wellington and Szczerbinski (2007), p. 39)

According to Lester (2005) the role of theory in mathematics education research (and therefore probably also in physics education research) should be discussed.

Niss have in a 2005-article discussed the concept and role of theory in mathematic education research, which for this discussion bares many similarities with physics education research.

Niss divides the role and function of theory into four categories: *an overarching theory*, *a theory for organizing a set of specific observations and interpretations*, *a terminology-providing theory*, and *methodology-providing theory*:

The overarching theory is a framework where teaching-learning situations are to be viewed and approached based on the chosen theory. Its top-down in the sense that

> [...] the theoretical framework is given before and outside the specific piece of research in which it is being put to use. In principle - albeit not so much in practice - this implies that the only objects, situations, phenomena, and processes considered are ones that are permitted by and visible from the theoretical framework.
>
> (Niss (2005), p. 8)

Research based on such overarching frameworks, I claim, primarily serves as

[4] American Association of Physics Teachers

tests of the theory in play. Niss's concept of an overarching theory overlaps with Lester's theoretical framework.

Theories for organizing a set of specific observations and interpretations, are on the other hand button-up in the sense that they serve as frameworks for looking at data which is not collected according to a theory-based design. 'Grounded theory' is the classical example of this kind of theory. These theories serve as meta-theories on how to let a theory emerge from a concrete analysis of data collected based on a general methodology. These sets of theories have relations to Lester's practical framework, but are not overlapping.

Terminology-providing theories are theoretical frameworks which opposed to the previous two types serve as a catalogue of terms, concepts and distinctions, which can be a place-holder, organizer or clarifier for reflections or observations, which beforehand without the theory were not easily articulated. These sets of theories have relations to Lester's conceptual framework.

Finally, *methodology-providing theories* offer methodologies for (empirical) studies, understood as a help to design and analyse data collections, whether these are interviews, video recordings, questionnaires etc. There also exist meta-theories of this kind: "Meta-theoretical considerations propose method triangulation in empirical research so as to avoid biased interpretations of data caused by a research instrument in itself." (Niss (2005), p. 9) Connecting this to Lester, some theoretical frameworks can provide methodologies for interpreting data. But this is not what Niss intends, since these methodology-providing theories to a larger extent should be understood as meta-theories of how to connect data interpreted with different methods (triangulation) which Lester states would normally not be accustomed within a theoretical framework.

Having provided the reader with this categorization of the role and function of *theory*, Niss then gives a critique of the use and mis-use of the concept of theory in the current research in mathematics education research:

> ... when looking at lots of examples of actual research there are numerous cases where a theory is in fact being invoked, but where the relation between the theory and the specific piece of research seems to be missing, i.e. the research is carried out without really involving the theory which is being invoked. This means that references to theory tend to be rhetorical.
>
> (Niss (2005), p. 9)

He then asks what the reason for including theory to the research is, and answers himself it serves as an order of legitimizing the research done, to increase its credibility, or to state a membership to a sub-community of the researchers which seems desirable. Either way, this is unfortunate.

It seems in physics education research that the concept of theory is less used than e.g. in mathematics education research, maybe due to the different understandings of theory in the two research fields of physics and mathematics, respectively. Therefore the concept of models seems to be more used in physics education research. Models can be understood as

> [...] tools (i.e., forms, heuristics, rules, schemata, classification patterns, and interpretative views) for the design, and possibly also for analysis, of instruction and its planning and preparation. [...] Models range from theories about general education for the future, for the structuring of curricula and teaching media, and for the daily preparations of the individual teacher.
>
> (Westbury et al. (2000), p. 48)

This understanding of 'models' share many similarities with the above mentioned concept of theory, and the difference in wording should not be taken as much more than a different tradition in the understanding of the concepts in the related disciplines.

2.1.6 Methods and methodologies

Increased understanding of issues related to physics education research can be gained by use of theories and/or empirical data (and most often when these combine), as is also the case of the natural sciences. Now that frameworks and theories have been investigated and discussed, empirical data and within this methods and methodology should briefly be touched upon. The complexity of understanding these concepts seems to be much less profound than understanding the concept of theory. Therefore not said that empirical data is not complex, but the underlying clarification seems less difficult.

The concepts of methods and methodologies are to some extent used in multiple ways. I will in the following distinguish between them by understanding methods of physics education research as the various ways of collecting and analyzing data. Methodology is then the science or study of methods; it is then the tools to reflect, evaluate and justify the choice of methods.

Wellington and Szczerbinski (2007) define methodology in the same way: "[Methodology is] the activity or business of choosing, reflecting upon, evaluating and justifying the methods you use." (Wellington and Szczerbinski (2007), p. 33)

The aim of methodology is then to describe and analyse methods, including their limitations, resources, suppositions and consequences and relating their potentialities to the twilight zone of the frontiers of knowledge (Kaplan 1973).

In this interpretation of methodology, the term concerns the self-critique of the methods of collecting data, the quality of the collected data and its analysis. In that sense, it includes a retrospect on the process of designing, collecting, analyzing and concluding based on the data.

Wellington and Szczerbinski (2007, p. 34) continue by setting up a number of questions a researcher in the field should always ask himself when writing up his empirical research:

- How was the study designed?

- Was the design appropriate?
- Why were particular methods of data collection used, and not others? Could, or should, other methods have been used? Why?
- How could the sample have been better?
- What was the quality of the data?
- Why were the data analyzed in the way they were? Could, or should, other methods have been used? Why?
- Can one 'generalize' from the data (extrapolate the findings to different situations)?
- How did the researcher affect the data collected?

Wellington and Szczerbinski (2007) recognize the tension between ideas, theories and data:

> [T]he connection between a researcher's ideas and theories and the data they have collected [is one issue which is always important]. In some ways this is still a mystery, mainly because it seems to rely on some sort of 'creativity', act of faith or blind leap from data to conclusions in certain cases. Are the ideas directly derived from their research data by some sort of process of induction? Or do they stem from creative insights, hunches and imaginative thinking? Probably a combination of both, one would suspect.
>
> (Wellington and Szczerbinski (2007), p. 9)

I find this statement very rewarding since I too have had many problems with understanding the process of having an idea or concept, which I wish to investigate, to collect empirical data and in light of the most appropriate theory or theories from the shelf use these theories as a guide *and* proof of my initial ideas, now based on empirical data. As posed in the beginning of this section concerning the nature of physics education research, articulation, critique, self-critique, systematization and justification are key terms in arguing for the choices made.

I have now touched upon the problematics in jumping from data to conclusions. This will be discussed to a much larger extent for the specific issues of this thesis later.

2.2 Literature survey

This section should be seen as a very short overview of the everlasting trends in research concerning laboratory work, along with a brief outlining of the current research trends in the field. Relevant literature will be discussed to a much larger extent when this is needed for further development of the research project. This is just to place my project within the present research literature.

The effectiveness of labwork activities as a teaching/learning activity have been discussed as long at it has been part of the science education, and still the role of labwork is discussed among teachers and researchers in the field of physics and science education.

Practical work in physics education has historically on one side been seen as ineffective, costly and useless and one the other side as the process defining school physics. Whether you place yourself in either of the two extremes or somewhere in between, it is a fact that labwork activities have been present in the school setting for more than 100 years, and nothing indicates it is about to leave the scene.

Internationally with the curriculum changes during the 1960 (e.g. the Nuffield movement), there were no end to the goals labwork activities were able to fulfil. In the late 1970s and early 1980s labwork activities changed status from the salvation of many of the problems related to science education to being regarded as almost useless, at least for fulfilling (most of) the long list of goals suggested some 10 years earlier. Several empirical studies showed that the students did not gain the knowledge, skills, processes and motivation which labwork activities were outlined to serve. Other studies showed that students did not understand the purposes of the labwork, and they perceived the purposes to be either *following the instructions* or *getting the right answer* (Lunetta 1998, p. 250). Further studies showed major mismatches between goals espoused for science teaching and behaviours implicit in science practical activities associated with major curriculum projects (Lunetta 1998, p. 251). In spite of this criticism many of the most critical voices still suggest the need of labwork activities in science education, simply since empirical investigations are one of the defining factors of science.

In the 1980s and 1990s the research society was seeking for solutions to rescue labwork activities by testing a variety of solution methods, where movements like constructivism (e.g. Goldbech et al. (1992)), predict-observe-explain (POE) (White and Gunstone 1992), open-ended labwork activities, authentic laboratory work activities (e.g. Roth (1995)) and enquiry based experiments are to be mentioned as a few. In these times laboratory work also experienced a boom in technological advancements for data collection and analysis, introducing concepts like micro-based laboratories (MBL).

Also there has for quite a while existed a discussion of whether labwork activities in school settings should be epistemological sound in relation to the epistemological stand of the natural sciences themselves. Arguments for this have been given by e.g. Hodson (1998). Arguments against this can be found in Kirschner (1992), when underlining "...the inherent flaws in considering and using the epistemology of the natural sciences as equivalent to a pedagogic basis for teaching and learning in the natural sciences." (Kirschner (1992), p. 273)

Today the discussion of labwork activities has slightly shifted. The effectiveness and motivational factors of laboratory work will always be discusses (e.g. Abrahams and Millar (2008); Abrahams (2009) for newer references), as well as research projects investigating the conceptual learning outcomes like heat, forces and electric circuits in the context of labwork activities seem to exist in all times (e.g. Abbott et al. (2000); Klassen (2009); Lindwall and Lymer (2008)).

Also some researchers still find use of the earlier described concepts, such as enquiry-based learning (e.g. Fay and Bretz (2008)); advanced data collection and data analysis technology and MBL (e.g. Scanlon et al. (2002); Barton (2005)), authenticity (e.g. Dinan (2005); Ng and Nguyen (2006)), but new ideas and concepts have come into play. Concerning science labwork activities in school settings (at all levels) a number of ideas and concepts are in the heat these days, such as virtual labs, scientific literacy, gender issues related to the laboratory, meta-cognition and nature of science (NoS), attitudes and interests, argumentation, competencies, etc. This list can be confirmed by recent literature reviews or scrolling through conference programs such as that of ESERA-2009, and do to a large extent resemble the general trends in science education research.

Internationally, science education researchers work on *computer based simulations* of labwork activities and *virtual laboratories*, see e.g. Kirschner and Huisman (1998); Evans (2000); Zacharia and Anderson (2003); Finkelstein et al. (2005); Francis and Couture (2003); Kieslick et al. (2005); Hatherly et al. (2009); Toth et al. (2009) both in relation to provide educational institutions which are poorly laboratory equipped with the possibility to manipulate 'data' through virtual laboratories (mostly by computer simulations, but also by remote control of laboratories e.g. placed at universities) or by comparing computer simulations and modelling to outcomes of hands-on laboratories.

Meta-cognition developed through laboratory work has also been investigated, and questioned, e.g. in Kung and Linder (2007). More about this in chapter 8.

There has also been a growing interest in the concept of *nature of science (NoS)*, which have been investigated in relation to labwork, see e.g. Wong and Hodson (2009).

Also *attitudes* and *interests* has been a growing field within PER, also concerning the laboratory work, see e.g. Cheung (2009); Holstermann et al. (2009). Perceptions, views and opinions have recently been discussed by Hanif et al. (2009). To some extent this also refers to the discussion of *gender* and science, also in relation to labwork activities has been investigated recently, see e.g. Danielsson and Linder (2009); Cheung (2009).

Argumentation in relation to labwork activities is in a few instances discussed, see e.g. Gott and Duggan (2007).

A movement has been emerging relating to specific labwork competencies in relation to labwork activities, such as the teaching of uncertainties, control of variables etc., see e.g. Duerdoth (2009).

Also labwork activities in relation to teacher education have been investigated, e.g. Nivalainen et al. (2010) detecting challenges among the pre-service teachers relating to the limitations of the laboratory facilities, an insufficient knowledge of physics, problems in understanding instructional approaches, and the general organization of labwork.

In Denmark, based on the very few researchers in the field of physics education, labwork activities have been given quite some thoughts recently (e.g. Schilling (2007); Goldbech and Paulsen (2004)).

Even though labwork in science and physics have been intensely investigated several years longer than I have been alive, there are still many questions to be asked and answered, where I obviously trust my research questions about linking the tradition of labwork activities with the purposes found reasonable for labwork activities, and the declaration of these, to be some of them. In part III and part IV relevant literature will be discussed.

Based on the work of making this very short review a few important things can be noticed:

Firstly, a large part of the research about labwork activities follow the general trends of science education, but everlasting discussions of the role, purpose, effectiveness and motivational factors of labwork exist throughout all years.

Secondly, very simply there exist two branches in the field: on one hand those that develop and test laboratory work activities based on various teaching-learning ideas, and on the other hand the critics, which blame the first group for not reflection upon the intended learning outcomes. Relations to these two types of researchers can be made to the curriculum and the Didaktik tradition, as these are discussed in section 2.1.1.

Thirdly, the research results still have poor influential impact on the current state of laboratory work in the science classrooms.

Finally, a lot of the literature concerning the purpose of laboratory work discuss it in very general terms, which is not easily related to the physics context, the specific topics within this and especially the specific labwork activities in play. A closer look on the discussion of aims and intentions with labwork can be found in chapter 5.

This finishes the introductory part, where the research questions are presented and placed in a larger frame.

Part II

Introduction to the empirical data

3 Methodological considerations

The methods in physics education research are the various ways of gaining empirical data and could be questionnaires, tests, surveys, interviews, observations (participant or non-participant), document collection, video, audio, etc. Some factors like a person's action, writing and saying might be directly observable with a minimum of interference, but other factors such as their thinking and deduction cannot be obtained, and can therefore be tried reached through e.g. tests, interviews, talk-out-loud problem solving, personal narratives and focus group discussions.

The methods chosen for this study are naturally strongly intertwined with the research questions, which the empirical data are to answer. But it also reaches deeper, since the choice of methods often refers to the underlying philosophical stands of the study, and the research methods should be correlated with the underlying views of e.g. epistemology, ontology and learning/teaching. Due to this it is important to have methodological considerations, such as this chapter is dedicated to.

Wellington and Szczerbinski (2007, p. 18) operate with contrasting philosophies in methods: positivist/interpretive, interventionist/non-interventionist, experimental/naturalistic, case-study/survey and qualitative/quantitative. As they state, it does not mean that a study cannot contain contrasting approaches, but that they have a contrasting nature, and therefore might give answers of a quite different nature.

I will draw forward a few of these contrasting methods to give an overview of the possible approaches and their differences, and more importantly discuss which of these methods are appropriate for answering the research questions.

Before going through the empirical research methods in relation to the research questions, a short comment on the chronology should be given. It has been an iterative process to develop the research questions and design and take in the empirical data, and therefore the collected data and the research questions fit together mainly because they are designed to do so. As is always the dilemma of reporting an iterative process, the study needs to be explained in a linear way, which is why it might feel somewhat fake to explain the empirical methods before the data and after the research question, when the truth is the process is a mess the writing is trying to untie.

3.1 Quantitative and qualitative approaches

In empirical studies of physics education research there is generally speaking a choice to be made between quantitative and qualitative approaches (and mixed-method approaches combining the two).

The word *quantitative* is concerned with quantity. *Quantitative research* then is a systematic way of investigating quantitative measures and their relations.

Most often quantitative approaches in education research consist either of questionnaires or tests (e.g. the ROSE survey, the PISE survey, analysis of written exams) which are investigating factors like opinions, interests, knowledge and skills. Otherwise quantitative research are collecting large test data samples, where a e.g. number of students have been exposed to various teaching approaches, where after they are tested on a number of measures, which can be compared by use of mathematical and statistical methods (e.g. the work on peer instruction (Crouch and Mazur 2001)).

Quantitative research is particularly good at showing tendencies in the data sample, which leads to hypotheses about students' or teachers' attitudes, opinions and knowledge. On the other hand, quantitative research is not always able to answer these hypotheses. This understanding can be retrieved:

> Research in social science is accomplished by use of qualitative and/or quantitative methods, which occasionally are termed as two 'tracks': a track for interpreting meaning and a track for creating meaning. [...] While qualitative methods bring the condition of social phenomena to focus, the use of quantitative methods aims for the distribution and statistical connections of phenomena.
>
> (Olsen (2002) p. 9, own translation, original citation marks.)

Quantitative results are very often producing conclusions used to affect policy makers within the education systems. Also, since mathematics and most natural sciences are dealing purely with quantitative approaches it is natural for many mathematics and science education researchers, coming from a background in mathematics or natural science, to wish to continue with these familiar methods in their research of education.

Qualitative, on the other hand, means concerned with quality. *Qualitative approaches* aim to answer hypotheses, like questions of *why* and *how*.

Qualitative research sets out to achieve in-depth understanding of the human behaviour, in the case of education research the processes and obstacles of teaching and learning. This is on the cause of the possibility to quantify. "Generally speaking, qualitative researchers are prepared to sacrifice scope for detail." (Silverman (2005), p. 9).

Qualitative research is highly dependent on the researcher, both in relation to collecting (or making)[1] the data, analyzing the data, and concluding based on the data.

3.1.1 Qualitative and quantitative choices for this study

For the first research question

Which potential learning outcomes does the laboratory work activities commonly used in physics in the Danish Gymnasium hold?,

two sub-questions need to be answered beforehand, namely:

- *Which arguments for doing labwork activities in a school setting exist?*
- *Which labwork activities builds up a series of commonly used labwork activities?*

The first is to be investigated through analyzing the curriculum and searching through relevant research literature, and therefore should not be seen as an empirical investigation of labwork activities, teachers or students (see chapter 5 for an answer of this sub-question). The latter - development of a labwork series - on the other hand is to be done based on empirical sources. Since the task is to develop a *typical* series, obviously quantitative methods are to be used to make the series as representative as possible. As an alternative to this approach, the series could have been identical to a series from a single teacher, which would then be truly authentic, but on the other hand, a justification of its representativeness would be limited. For this sub-question, it would not be reasonable to sacrifice scope for detail.

For the second research question

What is (if any) the impact on the students of a declaration of the teacher's intended learning outcomes of the specific labwork?

this also consists of components, which are to be investigated using different methods. Both the teacher's level of declaration of the intended learning outcomes of the specific labwork, as well as the question of possible impact of a declaration of the intentions on the students need to be investigated. Therefore both the teachers and their views on and presentation of their intentions *and* the students' reactions should be investigated.

The investigation of the second research question is empirical in nature, and should therefore be answered through analysis of empirical data. Having settled this, the next question to be answered is which type of data (quantitative or

[1] For this discussion see e.g. Petersen (2009).

qualitative) could serve the answering of the research question. Either choice would provide the study with different types of answers.

The way the question is posed heralds a qualitative approach, but it is still interesting to investigate which types of answers could be reached with quantitative methods.

Going for a quantitative answer, one could ask the teachers to answer a questionnaire concerning their degree of declaration of their intentions, but the interpretation will always be limited to trusting the teachers' answers to be true to their teaching, which will be questionable. Concerning the students, the impact could be interpreted purely as the students' ability to answer a certain type of (written) test, but it would not be possible in any way to justify how the answering had any kind of correlation to the done laboratory work, if these were not observed. Otherwise, in the same way as for the teachers', the students could be asked through a questionnaire for their experiences with laboratory work, and this again will be a questionable way of detecting impacts. Through quantitative investigations, like those just described, no insight into the students' direct response to the labwork and the declaration of its purpose could be gained, and it is therefore obvious to choose a qualitative approach for answering the second research question.

Going for a qualitative answer, a number of the issues stated for the quantitative method will be taken care of, but on the other hand qualitative studies has other issues. In the following section the chosen qualitative case studies are looked into.

3.2 (Comparative) case studies

As explained in the previous section, for the main empirical data collection intended for answering the second research question, qualitative investigations are the natural choice due to the nature of the question. Therefore a large survey (as opposed to case studies) is neither possible nor reasonable for answering the question posed. Instead studies of four cases are done. In chapter 4 the four cases will be investigated and compared. Therefore a discussion of case studies and comparative case studies are in place.

What is a case?

> Case studies are a common way to do qualitative inquiry. [...] Case study is not a methodological choice but a choice of what to be studied.[...] As a form of research, case study is defined by interest in an individual case, not by the methods of inquiry used.[...] For a research community, case study optimizes understanding by pursuing scholarly research questions. It gains credibility by thoroughly triangulating the descriptions and interpretations, not just in a single step but continuously throughout the period of study. [...] A case study is both a process of inquiry about the case and the product of the inquiry.

(Stake (2005), pp. 443-444)

Stake categorizes case studies in three, depending on the interest in the case in itself, or as a case among many to be generalized from. The three categories are *intrinsic cases*, *instrumental cases*, and *collective cases*.

An intrinsic case is a case, which has an interest to the researcher by itself - not necessarily caring what it is a case of.

Instrumental cases are - as opposed to intrinsic cases - of interest due to its ability to say something more general of the issue on the line. The case is of secondary interest, it plays a supportive role, and it facilitates the understanding of something else.

As the instrumental case studies sought to redraw generalization, there might be problems in justifying the general from a single case, and one could move on to collective cases. It is instrumental study extended to several cases.

As already told, this work is based on the investigation of four cases. As the research question is not related specific to a particular single case in the form of an intrinsic case study (as would have been the case, if the research question was something like: *What is (if any) the impact on student X of a declaration of teacher Y's intended learning outcomes of labwork Z?*).

The hoped outcome of the study is to be able to redraw a generalization of the issues investigated. The interest is not particular in the case (or cases itself), but the cases are each of them interesting, since they serve the purpose of saying something more general about the issue on the line.

As argued by Stake, through an instrumental case study it is possible to redraw a generalization based on a single case, but as one of the case students in this thesis study put it[2]:

908 **David** Daisy [second student in the focus group] needs to find out how many
909 Gymnasium students are going out partying Thursday night and only asks
910 Dana [third student in the focus group]. All Gymnasium students go out.

This comment naturally occurred during a labwork in a physics classroom, where quantitative measures are known to be the scientific language, but still as a physicist I find it difficult to redraw generalizations based on a single case. That does not mean I do not understand the point of a single case study, I just find them better justified for intrinsic cases, which - as argued - this research question is not.

By stating this, I land in the pitfall of believing one of Flyvbjerg's five common misunderstandings about case-study research, as these are presented and argued against in (Flyvbjerg 2002).[3] His arguments against why one cannot

[2] David is one of the case teacher Derek's students. The statement is given while working on a halfwidth labwork. The line number refer to the transcript report

[3] His five misunderstandings are : (a) general, theoretical (context-independent) knowledge

generalize on the basis of a single case are based on e.g. Galileo's theory of falling bodies[4], and he ends out by concluding:

> One can often generalize on the basis of a single case, and the case study may be central to scientific development via generalizations as supplement or alternative to other methods. But formal generalization is overvalued as a source of scientific development, whereas "the force of example" is underestimated.
> (Flyvbjerg (2002), p. 228)

Trusting Flyvbjerg (that one *can* generalize from a single case), then by logic deduction, one can also generalize from four cases. The real problem occurs, if it is believed that one cannot generalize from a small number of cases (such as four). This discussion is taken up at the very end of this thesis, when the cases and the conclusions drawn are known.

As discussed by Stake (2005, p. 444) it is important to declare the boundaries of the case (or cases) to be studied. The cases in this study are not the teachers or the students or the groups of students, but the case is the specific labwork activities, which the teachers and the students are engaged with. The investigation of a number of specific school labwork activities should result in a generalization about the issue of labwork activities as teaching activities.

There are (at least) three ways to investigating labwork activities, namely from the content of the labwork, from the teacher and from the students, and each of these are a necessity for studying the case. This threefold division can also be detected in the second research question, where it is necessary to investigate the content through the intended learning outcome, the teacher through the degree of declaration, *and* the students in their respond to the content and the teacher (the impact on the students).

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is more valuable than concrete, practical (context-dependent) knowledge; (b) one cannot generalize on the basis of a single case; therefore, the case study cannot contribute to scientific development; (c) the case study is most useful for generating hypotheses; that is, in the first stage of a total research process, whereas other methods are more suitable for hypotheses testing and theory building; (d) the case study contains a bias towards verification, that is, a tendency to confirm the researcher's preconceived notions; and (e) it is often difficult to summarize and develop general propositions and theories on the basis of specific case studies.

[4] "...to conduct the ultimate experiment, known to every pupil, whereby a coin or a piece of lead inside a vacuum tube falls with the same speed as a feather. After this experiment, Aristotle's view could be maintained no longer. What is especially worth noting in our discussion, however, s that the matter was settled by and individual case because of the clever choice of the extremes of metal and feather. One might call it a critical case; for if Galileo's thesis held for these materials, it could be expected to be valid for all or a large range of materials. Random and large samples were at no time part of the picture." (Flyvbjerg (2002), pp. 225-226)

3.2.1 'Naturalistic' and 'experimental' approaches to research

Having argued for comparing cases to be the way for empirically answering the second research question, one could start doubting whether it is reasonable to compare cases, where 'everything' is different. In physics one should always carefully make sure to have as much control of the independent variables as possible, since they might all affect the measured variable, and therefore making it impossible to draw conclusions as to whether the volume increase was due to pressure change, temperature change, change in magnetic field, change in moisture in the air etc. etc. Is a detected impact on the students a function of the degree of declaration, or is it due to other factors like the school, the topic, the apparatus, the students earlier achieved skills, knowledge, interest etc.?

These considerations have resulted in the collection of two types of observed cases: the *naturalistic cases* and the *experimental cases*.

The naturalistic approach deals typically with observations, where the researcher is not trying to influence the data, as opposed to the experimental approach, where the researcher performs a more or less controlled experiment with the data sample (see table 3.1).

Table 3.1 Naturalistic and experimental approaches, inspired by Wellington and Szczerbinski (2007, p. 21)

	Naturalistic	*Experimental*
Setting	Natural setting like workplace, home, street, classroom	Where the researcher finds it most suitable
Primary data-gathering instrument	The researcher	Surveys, questionnaires, the researcher, etc.
Methods	Qualitative (not exclusively)	Quantitative (not exclusively)
Sampling	Purposive sampling	Representative or random sampling
Design	Design tends to unfold/emerge as the study progresses and data is collected	Clear design prior to the data collection
Theory	Theory tends to emerge from (be grounded in) the data	Based on an initial hypothesis, which the research sets out to support or falsified

As was also the case for the naturalistic case studies, there are a number of possible problems connected to an experimental approach. First, though trying to eliminate them, it is impossible to control all the variables. The experimental approach is often done as a comparison analysis, where the two samples are not similar (every person is different in a much more complex way than every electron). The solution to this problem is often to do experimental studies with a large number of participants, so their internal differences will be levelled out.

This then leads to a severe amount of data to be collected and analyzed, making it unlikely to go into depth with the cases in the same sense as for a naturalistic case study with much fewer cases.

Second, there is the possible problem of the Hawthorne effect,[5] which is the tendency that when a group is chosen for special observation, their performance will increase, though nothing is changed (the placebo effect in education research). If the students know they are exposed to an experiment, which are intended to improve their learning, the effect will be positive per se.

The first two collected cases for the empirical part of this work can be characterized as naturalistic cases. I participated in the classes and observed what happened, but I did not try to make the teachers change their practises.

The latter two cases could on the other hand be characterized as experimental, since I asked each of the two teachers to do two labwork activities, which were as like as possible (same school, same teacher, same topic, more or less the same equipment, same class, same observed group and same time allotted for the labwork), but where the degree of declaration was as different as possible.

Since the second research question does not seek to be descriptive (as intended to describe the current reality, to investigate an average labwork, or to give a perfect example of the most common situation), the cases are not chosen in order to be the most common. The cases should do their best to answer the research question investigating the effect of a declaration of the labwork purposes, and therefore the better choice is to find teachers, who are willing to engage in the study than an average teacher (whatever that is).

As noted by Stake in the quote at page 51, case studies are not a choice of methods, but a choice of what to be studied. So up until now, I have not discussed *how* to collect the data for answering the question, but merely made more explicit what it is to be studied.

[5] The Hawthorne effect is any initial improvement in performance following any newly introduces change. It was named after a study of 1924 of the productivity of factory workers at the Hawthorne factory in Chicago. Two groups were separated from the rest of the factory workers. One group was the control group, which did not experience any change. The other group was the experimental group, which experienced changes in there working conditions (illumination, humidity, temperature, and rest periods). The results were that the productivity increased for the experimental group, both when their working conditions were decreased or increased (shorter or longer rest periods or increased or decreased temperature). As was also found, the control group, where no changes was occurring, had an increase in the productivity, until the situation became familiar to the two groups.

3.3 Interviews, observations and document collection

Up until now, this chapter has been concerned with quantitative versus qualitative approaches, and for the second research question the reasons and possible pitfalls of choosing a collective case study approach (naturalistic and experimental). But no detail has been given on which methods for collecting the relevant data have been chosen. When doing case studies, there are an enormous amount of methods, which to my best knowledge more or less boils down to the collection of artefacts (documents, power-point-presentations, exam papers, notes, concept maps, etc.), interviews (focus group, group, or single person, structured, semi-structured, or unstructured, longitudinal or single instance, etc.), observations (audio, video, or field notes, participant or non-participant, etc.), and talk out-loud problem solving (Yin 2003).

Firstly, it is relevant to understand which intended learning outcomes the teachers have for doing the specific labwork, and to which degree they declare it to the students. It has been found useful to collect this information by three different methods: (a) interview with the teachers asking for their view of the possible learning outcome of the labwork and whether they are going to declare it for the students (along with many other questions to clarify the background of the teachers, their view on physics, their view on physics teaching, their view on the class, etc.); (b) analysis of the labguides for indications of their intended learning outcome and the degree of declaration; and (c) the teachers' introduction of the labwork to the students, again to gain insight to their intended learning outcome and the degree of declaration. Based on these three different types of data, triangulations can be made to reveal the teachers' intentions, their degree of declaration and to which extent their teaching resemblance their statements during the interview.

Secondly, it is relevant to understand the impact (or lack of impact) on the students. The concept of 'impact' is purposely a much more fluffy concept, and the most proper methods and the analysis afterwards have therefore been more difficult to determine. As it is important to notice, the question is not whether the students learned what the teacher intended them to learn. Learning of complex concepts cannot be categorized as either learned or not learned. E.g. one cannot detect when a student have learned variable identification, since this is a process of possibly several years, and most likely never fully grasped. Instead it is possible to detect to which extent the students make use of the concept. But what if the teacher does not have a declared intended learning outcome? What is then to be looked for?

This dilemma has been solved by video recording the students during the labwork and categorizing their actions and talking. Then the levels of each category for all the cases are compared and correlated to their teacher's degree of declaration. Also the video recordings are analyzed in order to gain insight into the quality of the students' discussions and reflections during the labwork, in relation to the intended or potential learning outcomes of the labwork task.

Also to detect differences and possible correlations, the laboratory reports are detected to see to which degree the students respond to the teachers' declaration (if such exist) and to which degree they accept them as a reasonable purpose of the labwork.

Finally, after the labwork activities, the students were interviewed to gain insight into their views of physics, labwork, their teacher etc., and to get to know their plans of further education/career.

4 Empirical investigations of teachers' labwork purposes

This chapter contains an introduction to the empirical data collected throughout this PhD work. A number of different labwork tasks with different teachers, within different topics, at different school levels, at different schools, and even in different countries have been observed. Here the kind of collected data and the purpose of collecting them are described. These are divided into two categories: *pilots* and *in-depth* investigations.

The pilots were not intended to give me data to be analyzed in order to answer my research questions, but instead they were meant to give me an overview of the present state of the labwork activities in the Gymnasium from an observer's point of view, as well as serving as the basis for informed choices as to which physics level to investigate (C, B, or A). Also the pilots were meant as a test of the possibility to collect useful data using different tools such as field note taking, audio recording, video recording, interviewing, etc. Finally, one of the pilots changed my view of alternative, student-evoked, 'authentic', open-ended, cross-disciplinary labwork activities, since it showed me the many possible pitfalls of such tasks, and made me turn my attention towards the more often used labguide-based labwork activities.

The in-depth investigations are data serving three purposes: as the generator of research questions, as a justification of the underlying premises of the research questions, and as the main tool for answering them. In this chapter the focus (in the reporting of the in-depth investigations) is only on the teachers: the interviews, their labguides, and their introduction to the labwork activities. The description and analysis of the students are left for part IV. The reasons for this division of teachers first and students later are three-fold:

Firstly, it is seen as a service for the reader. Many PhD theses are quite heavy towards the beginning, since all theoretical and methodological considerations are presented before the empirical data are shown. This often causes the reading of the thesis to be almost insurmountable.

Secondly, there is a number of underlying premises in the research questions; such as the existence of a series of commonly used labwork activities, that not all teachers declare their intended learning outcomes of a labwork task, that not all teachers are even aware of their intentions with specific labwork activities, or that not all teachers are finding a need for having clear-cut intended learning outcomes for the particular labwork in play. The focus on the teachers will provide a clarification and justification of the underlying premises, which therefore serves as a justification of the research questions.

Thirdly, focusing on the teachers has given rise to the asking and answering of interesting questions besides the research questions. These conclusions deserve to be given before intertwining and thereby blurring them with the data concerning the students.

First an overview of the different data collections is given - both pilots and in-depth investigations - and thereafter showings from the in-depth cases: the teacher interviews, the labguide and the teacher introductions. These showings serve to clarify the declaration level of the case teachers' intended learning outcomes.

4.1 Pilots

Pilot investigations were done both in Denmark and during the exchange visit overseas. Here the various pilots and their role for the dissertation is summarized, ending out with a longer description of one of the pilots, which came to mean something more to the project. This pilot is called 'PE physics'.

4.1.1 Short pilots

An overview of the short pilots is given. This overview serves the threefold purpose of teaching about the state of labwork in schools, being the basis for a choice of the physics level for the in-depth investigations, along with investigating the observational methods and their use for this study.

Prism labwork

This labwork was a third year A-level physics class in the Danish Gymnasium concerning prisms. The students were provided with a laser pointer, various prisms and a protractor. The task was to measure the angle of diffraction in the prism and find the deviation from the theoretical value.

This pilot observation was used to investigate how well field note taking worked. It was found that the value of the data was very poor, leading on to a choice of video recordings from then on. Also this work made served as a basis for not changing focus groups, but to stick with one group throughout all labwork activities. Finally, it became apparent how students at the A-level had an enhanced knowledge of labwork strategies, wherefore they discussed their work very little during the laboratory activity, providing limited data.

During this labwork it seemed to be that the students and the teacher were agreeing on thinking of the labwork task as being developed to fill in a need for a labwork activity in the topic of optics, and therefore there was no need to discuss the teacher's intended learning outcome of the particular labwork. No direct data supports this claim.

Gravitational constant

This observation in a first year class of students not intending to follow the physics program after the mandatory first year concerned masses and the gravitational constant.

The labwork activity was about measuring the force by a spring force-meter for different masses and then comparing the results with the weight of the masses measured on an electronic weight.

The teacher had a twofold declared purpose of both making the students feel able to and have fun with doing labwork activities in physics *and* learn to make simple data treatment by use of computer software.

For this labwork only one group was followed, which was found much more fulfilling. Since the teacher's intended learning outcome concerned very simple data handling techniques, it was on the basis of this labwork chosen to follow students having physics above the mandatory level. The students both engaged fairly enthusiastic with the task *and* learned to use software for data treatment, so in that sense the intended learning outcomes were met.

4.1.2 Australian pilots

During my exchange visit I worked with the International Centre for Classroom research. They operate with a special way of collecting data. The centre visited a science class at lower secondary school (8th grade) for all modules related to a specific content, in these cases adaptations in biology and state of matter in physics/chemistry. The data collection was done by four video cameras: one on the teacher, a wide-angle camera on the entire classroom, and two cameras on two focus groups of each three students. The video recordings were backed up by audio from wireless microphones attached to the teacher and a student from each of the focus groups along with a class microphone to pick up audio from other students of the class. These video and audio recordings were simultaneously synchronized and immediately after class the focus student and the teacher were interviewed while they were themselves scrolling through the video recordings of the class activity in order to discuss specific instances during the video-recorded module. These interviews were again video recorded. This was a very technical and man-power demanding task, and to justify it (and pay for it) each data collection was used by up to ten researchers (including PhD students) with various research interests related to science education research.

Though the data collection and the environment around the data treatment were very rewarding, such a data collection method is no way possible as a single person observer. I participated in the video recordings in class, the interviews and the data analysis. I viewed this period in my dissertation time as an apprenticeship in science education research related mostly to methods and methodologies. I learned valuable knowledge about observation techniques, interview techniques and planning of interview guides, transcription techniques, data categorization techniques, etc.

But I also came to think about the teaching and learning going on during the observations. Especially two episodes stood out.

The first was an activity taking place in the adaptation sequence. Here the teacher provided the students - divided into groups of four - with various devices such as spoons, clothes pegs, needles etc. which should play the role of bird beaks as well as a number of 'bird foods' like raisins, corn and nuts. The students were then to note the amount of the different food supplies they could catch within a certain time sloth with the different 'beaks'. This should teach them how some birds were very effective in eating a specific food type and other birds were able to eat practically everything. If a specific food supply would no longer be present in the bird's habitat, the bird having specialised its beak for a certain food supply would become extinct, while a less specialised bird would just change its food choice. I thought the task had a lot of potential in it, but the teacher did not encourage an afterward discussion about the pros and cons of this model, and the general conclusion would be that birds with un-specialised beaks were the only once to survive evolution, which obviously is a con of the model. The interviewed students afterwards mostly emphasized the fun and competitiveness of the task, which correlated with the answers of the teacher.

The other activity was in the state of matter sequence, where the students were asked to boil a cup of water by a Bunsen burner and measure the temperature of the water every 30 seconds. The task was designed by the teacher so the students would learn how the temperature more or less increased linearly until the water started to boil, where after the temperature becomes stable around 100 degrees. The students were though not asked to draw the graph of temperature versus time, and therefore they would not reach this conclusion. In the research group we had lots of discussions about this very used task, and how it funnily enough could be interpreted as the mere task of teaching students to boil water. This led me on to consider how many labwork activities were done without reaching for an outspoken learning outcome.

4.1.3 PE physics

At the very beginning of the dissertation work a 2nd year level B physics Gymnasium class was observed doing a special kind of labwork. The work concerned a cross-disciplinary full day work including PE (physical education/sports), physics and English.

No involvement in planning or execution of the exercises were done. No pre or post interviews with neither teacher nor students were conducted, and the lessons before the full day exercise and the Anglophone presentations reporting the activity were not observed.

Two teachers were assigned for the task, the class' physics teacher, and the class' PE teacher (who was also a physics teacher, just not for this particular class). Prior to this day the class had been divided into groups of typically 3-4 students, and each group had chosen a sport discipline, e.g. basketball, weightlifting, and table tennis.

Only the class' physics teacher was present during the introduction. Each class was urged to find the sport gear relevant for their discipline. Standard digital video cameras were distributed to the groups, and each group was encouraged to make video recordings of their sport activity for later analysis.

The first four hours the groups spend on recording hours of video of basketball shots, table tennis smashes, etc. The table tennis group made an introductory effort of finding out all about the rules of table tennis, making sure the video recordings would be in line with international table tennis regulations. The basketball group instead spend a long time trying to make a complicated shot, including the player to run towards the loop, jump and score. If the ball did not go through the hoop, the video recording was discarded. As they stated, they wished to earn good grades for this project, making it important that the data was of high quality, which for their case equalled a perfect 3-point shot.

Generally the atmosphere was positive. The students were engaged in the task, and they felt the project was meaningful also in line of the physics and not only the sports, highlighted by the quote concerning the grades.

After the first four hours, the students returned to a computer environment at the school library, where they loaded the frames of the recorded videos into an analysis program. Each group found the program quite easy to use, and was able to load the frames and on each frame mark the point of interest (e.g. the ball), giving the possibility to make graphs of the acceleration, velocity and position in either the x- or y-direction or the magnitude as a function of any of the others or of time.

Only here the students became aware of the un-necessity of having hours of video recordings, of having the perfect 3-point shot, or of having known the rules of table tennis (since for the perfect smash, the table tennis ball was only present in two of the video frames). This led to frustrations among the group members, each accusing the others for not having paid attention of the purpose of the task during the introduction. They did not know which graphs were interesting to plot. One group found great comfort in a perfect linear fit to a graph of the velocity in the x-direction as a function of the velocity in the x-direction.

The students had no clear idea of how to perform the data treatment or why. This led to many discussions both within the group and with the teacher, not about physics, but about the poor design of the task.

This task had a great impact on the formation of this study. Originally hearing about the task, it included a long list of the features, which was perceived as of great value: The students had a high level of co-determination; it was open-ended and cross-disciplinary. Therefore it was really surprising to observe the general student frustration when the data handling started. Reflections about these kind of tasks and the reasons for student frustrations were analyzed according to the Brousseauian term of *didactical contract* (Johannsen and Jacobsen 2010 2009a), leading on to concluding the importance of declaring the difference of this type of task compared to the type of labwork activities, which the students are already familiar with.

4.2 In-depth investigations

Also four in-depth investigations were conducted, all build upon the same data collection design:

- Introductory interview with the teacher
- Observations and audio-recording of the classroom activity in all the lessons within the particular topic
- Video recordings of one or two focus groups of students while doing the labwork activity
- Student group interview with focus group students
- Collecting of the reports after correction by the teacher.

The interview guides for both the teacher and the students interviews can be found in appendix B.

In the in-depth cases, two cases are naturalistic in the sense I as an observer do not try to influence the design and conduct of the labwork activities. The latter two cases are experimental in the sense, that I have cooperated with the teachers in order to design the task to give me the type of data most well-suited for my data analysis. To make sure as few parameters as possible were changed, I asked each of the two teachers to do two labwork activities, which where as like as possible (same class, same topic, more or less the same equipment, same observed group and same time allotted for the labwork), but where the degree of declaration were as different as possible. See also the discussion in section 3.2.

The teachers in the naturalistic in-depth observations are coming from different schools, and are working with different topics. Several reasons for this choice can be given.

Firstly, I wished to allow the teachers to choose for themselves their classes, topics and labwork activities. This allowed me to look at teachers, who possibly have given the intended learning outcome of their chosen labwork a great deal of thoughts, since this particular labwork is the one among many, they have chosen to show me. These teachers invited me in, since they were proud of their teaching of this particular labwork.

Secondly this question of the teacher's purpose is not (necessary) connected to the topic of the labwork. As an example, a teacher might have an intended learning outcome of a labwork to be related to the skill of extracting results from data represented by graphs. This intended learning outcome is not connected to the topic, but some labwork activities might be quite well-chosen for this purpose, whereas others do not even include representing data in graphical forms. This argument serves as a justification of the choice of using different topics for the case study investigations.

For the experimental cases, both teachers did the same two labwork activities, since these are found to be ideal for the purpose of comparison. It does not make sense to make students repeat a labwork, so two labwork activities as identical as possible and still reasonable to do in the school setting are to be recognized. Here the choice fell on the halfwidth and halftime experiments within the topic of radioactivity, since they share equipment, data handling methods, etc.

4.2.1 Alice - ideal gas law

Alice is a female teacher with 15 years of teaching experience in the Gymnasium. Alice teaches physics and mathematics, and she has been teaching physics every year.

Alice has an educational background from Copenhagen University, where the teaching is based on lectures, instruction classes and a few laboratory classes with very little project work activity. Alice studied physics and mathematics at the under-graduate level and did her master in physics. Alice has a PhD in cosmology before starting to work in the Gymnasium. This carrier choice was deliberate; she did not wish to continue in academia after finishing her PhD work. Based on student jobs in the Gymnasium, she made a considered career choice, and has not regretted it.

For six months, while working part time as a Gymnasium teacher, Alice had a job working with developing in-service courses for teachers and developing teaching materials. She decided after half a year to go back full time to teaching, because this was the place that felt most fulfilling for her.

Having experienced the reform implemented in 2005, she is generally positive towards it. She especially likes how the reform demands the teaching in physics to be related to other areas, like society issues. Alice is very aware of her teaching ideally should be improved every year. She does not allow herself to reuse anything from a previous year unless she has reflected upon it once more.

Alice is teaching in a school in the suburbia Copenhagen area. The student present at this school generally comes from good social backgrounds with highly educated parents. This can be seen at the school grade point average of 7.6 (2008 numbers), which is large compared to the country average of 6.8. The school has a low level of ethnical mixing.

Alice's class is at their 2nd year, where physics is optional. The observation takes place shortly before Christmas. The class has 29 students, 9 females and 20 males. Alice's impression is the class generally functions well socially as well as vocationally.

Alice invited me into her class while working with states of matter. The labwork I observed concerned the ideal gas law. As the class last year had done an experiment of pressure as a function of temperature, and Alice did not want to make them repeat the experiment, the class is asked to do three experiments:

- the pressure as a function of volume under constant temperature and amount of substance (experiment 1);
- the pressure as a function of the amount of substance under constant temperature and volume (experiment 2);
- the volume as a function of temperature under constant amount of substance and pressure (experiment 3).

For the first two experiments the students are to use a computer-based pressuremeter and a syringe, and for the third experiment, they are to use a pipette with an air bobble trapped in paraffin wax.

During the labwork the class is split in two parts, so only half of the class were present at the school laboratory at a time. Each of these parts is again divided into groups of 2 or 3 students to be working with the labwork activities together. The students are given 2×1 module of 90 minutes to do the labwork. The modules are separated by a week. A report containing all labwork activities conducted over the two modules are to be handed in as group reports, where the groups are to be identical with the working groups during the labwork task itself.

An introductory interview with Alice were conducted. All lessons about the topic of state of matter prior to the labwork were observed. Due the parting of the class it was possible to observe and video record two groups doing the labwork activities. Straight after both labwork modules for both groups student group interviews were conducted. The lab reports were collected after these have been corrected by Alice.

The labwork in Alice's class is a naturalistic case.

4.2.2 Burt - conservation of mechanical energy

Burt is a male teacher with 32 years of teaching experience in the Gymnasium. Burt teaches physics and mathematics. Burt has been teaching either physics or general science every year.

Burt has an educational background from Copenhagen University. Burt entered his university education with the deliberate goal of becoming a Gymnasium teacher in mathematics and physics. Burt did his undergraduate in mathematics and physics and his master in mathematics. Burt has been involved with a number of projects both at universities and for the Danish Ministry of Education, and has for a number of years been engaged in in-service courses for mathematics teachers.

Burt is generally happy with the 2005 reform, where he thinks the curriculum for physics is more or less as he would like it to be. He is though not very happy with the exam form.

Burt works in a school in the rural area. The students come from a mixed social background. The school has a low ethnical mix. The school grade point average of 6.3 is below the country average of 6.8.

Burt's class is halfway through their second year of the Gymnasium, where physics is optional. The class has 24 students with 10 female students and 14 male. Burt's impression is that the class is well functioning socially. Vocationally his view is they are fairly good and quite interested.

Burt invited me into the class while working with forces and energy (classical mechanics). The class finished the topic by doing two labwork activities, one concerning forces and one concerning conservation of mechanical energy. I chose to follow the labwork of mechanical energy. This labwork was conducted on an air track. On the air track a cart was released from halt at one end of the air track, being pulled by a string attached to a weigh over a pulley, dropping from the other end of the air track towards the floor. The velocity of the cart at a given position was to be measured by a photo cell located at the air track, thereby allowing the kinetic energy to be calculated (the photo cell was shut off when a tab placed on the cart passed by). The change in the potential energy was measured by the position of the photo cell, since this allows calculating the drop height of the pull weight. Various features of the task were varied:

- the position of the photo cell
- the weight of the load mass
- the weight of the pull mass
- (the length of the cart's tab)

An introductory interview with Burt was conducted. All the lessons of forces and energy prior to the labwork was observed and audio-recorded. Due to a division of the class caused by a lack of equipment it was possible to observe two groups doing the labwork activities. The labwork activity runs over one module (45 minutes). Shortly after the labwork student group interviews with each of the two focus groups were conducted. The reports were collected after these have been corrected by Burt.

The labwork in Burt's class is a naturalistic case.

4.2.3 Charles - radioactivity

The intend with this observation was to make Charles do two similar labwork activities: one where he did not state his purpose/intended learning outcome to a higher extent directly, and one where he had an openly articulated declaration of the purpose of this specific labwork. I was to choose which purpose to declare based on his written labguide. The purpose of this experimental approach (as it is used by Wellington and Szczerbinski (2007)) was to detect - if any - which differences it made on the students' way of talking about, working with and reporting on the labwork. As the day of the labwork arrived, it became clear that he had not truly grasped the intentions, even though several discussions and email correspondences indicated he understood what was intended. Still the data is interesting, though not serving the purpose it was originally intended to.

Charles is a male teacher with 6 years of teaching experience in the Gymnasium. Charles teaches physics and mathematics. Charles has been teaching physics every year.

Charles has an educational background from Copenhagen University. Charles has had a large part of his elementary school teaching in Iraq, and then moved to Denmark continuing his education here. Charles did his undergraduate in astronomy and physics and his master in astronomy. Charles intended to continue working as an astronomer - possibly internationally - after his master degree, but due to family obligations he chose to transform his student job as a Gymnasium teacher to his carrier choice.

Charles works in a school in the suburbia Copenhagen area. The students come from a mixed social background. The school has a high ethnical mix. The school grade point average of 6.3 is below the country average of 6.8 (and the same as Burt's school).

Charles's class is halfway through their second year. The class has 29 students with 8 female students and 21 male. Charles's impression is the class is relaxed around each other and him, and they joke a lot. Vocationally he expects this class to be better than his previous class.

I planned with Charles to follow two labwork activities within the topic of radioactivity. The class finished the topic by doing two labwork activities, one concerning halfwidth of various radioactive sources through aluminium and lead, and one concerning halftime of a radioactive isotope of Barium. I chose to follow the same group for both pieces of labwork. Both labwork activities was conducted by use of a Geiger counter and a Geiger-Muller tube. For the halfwidth experiment, a radioactive source was mounted to a holder, and a number of aluminium or lead plates was to be placed between the source and the GM-tube, detecting the radioactive activity as a function of the width of the plates. For the halftime experiment, the GM-tube was to be placed in front of a container with radioactive Barium, and the number of counts pr. 10 seconds detected by the GM-tube should be noted, until the count number was close to the background radiation level.

An introductory interview with Charles was conducted. All the lessons of radioactivity prior to the labwork were observed. For this class, all students did the labwork activities at the same time. Since each group had to do two labwork activities, it was chosen to follow the same group for both pieces of labwork. The reports were to be collected, but the group chose not to hand in the last report concerning the halftime.

4.2.4 Derek - radioactivity

My intent with this observation was to repeat the experiment with Charles; that is to do two similar labwork activities, one where the intended learning outcome is not laid out clearly, and the other where it is. The purpose was to detect - if any - which differences it made on the students' way of talking about, working with and reporting on the labwork.

Derek did the same two labwork activities as Charles concerning radioactivity. Due to the special background of Derek, it was expected that he understood the intentions to a higher extent than for the case of Charles.

Derek is a male teacher with 3 years of teaching experience in the Gymnasium. Derek teaches physics.

Derek has an educational background from Roskilde University. He has a (very recent) PhD degree in physics education research. The final part of this PhD study was conducted while he worked as a Gymnasium teacher. Derek has deliberately chosen to work as a Gymnasium teacher during and after his PhD study, but are at the same time partly working with research in physics education at Copenhagen University. Derek is not sure his carrier will not change over the next years, but right now he is very happy with his choice.

Derek works in the same school as Charles (suburbia Copenhagen area, mixed social background, high ethnical mix and grade point average of 6.3).

Derek's class is halfway through their third year. They have had physics in the first year, and again in their third year, and are working to receive a B-level in physics (as is also the case of Alice, Burt and Charles). The class has 18 students with 10 female students and 8 male. Derek's impression of the class is that they are active and knowing a lot, but also some times rather lazy. Derek feels he is loosing three of the students in the class; they do not seem interested in physics and are cutting a severe amount of the classes.

Derek invited me into the class while working with radioactivity. Within this topic the students do the same two labwork activities as Charles; namely the halftime of a Barium isotope and the halfwidth of lead in relation to gamma radiation.

An introductory interview with Derek was conducted. All the lessons of radioactivity prior to the labwork was observed. Both labwork activities were observed as well as audio and video recorded. An interview with the students were conducted after the second labwork and the reports were collected.

4.2.5 Comparison of the in-depth investigations

Some similarities and differences should be outlined.

The first three teachers have a similar educational background from the same university (though with approximately 25 year span), and the last comes from another university and has a research background of physics education. All four classes are halfway through their B-level physics. The class size is rather similar, and the gender difference is for the three first cases in favour of more male than female students, and for the last approximately equal.

For the differences, the teachers have quite different years of experience. Burt have deliberately focused his education towards becoming a teacher, Alice made the choice of becoming a teacher after her PhD as the position she would prefer over other possible career choices. For Charles it became a way of getting a permanent position. For Derek this is possibly a temporary position, but a position he is very fond of. The labwork activities planned is also very different in the sense they are within different topics of the curriculum: state of matter, classical mechanics and radioactivity. The schools are located in quite different areas, and also have quite different grade point averages (Charles/Derek's and Burt's schools share the grade point average, Alice's is quite higher). A summation of the four in-depth cases can be found in figure 4.1.

Despite their differences, interesting things will emerge from comparing the teachers, the classes and the labwork activities.

As seen, the teachers are not expected to be representative. Alice has been engaged in developing in-service courses and producing teaching material. Burt has also been engaged in in-service courses, developmental work in math teaching and production of teaching material. Derek has a recent PhD degree in physics education research.

The teachers do not need to be representative in order to answer the research

Figure 4.1 Summation of the four in-depth cases.

	Alice	*Burt*	*Charles*	Derek
Case				
Case type	Naturalistic	Naturalistic	Experimental	Experimental
Teacher				
Experience	15 years	32 years	6 years	3 years
Education	Physics (math)	Math (physics)	Astronomy (physics)	Physics, philosophy
Carrier choice	First choice after PhD	Already determined when starting university	'Easy' fall back when research carrier did not happen	First choice after PhD
School				
School area	Suburbia	Rural	Suburbia	Suburbia
Social profile	Students with well-educated parents	Mixed social background	Mixed social background	Mixed social background
Ethnicity	Ethnic Danes	Ethnic Danes	Mixed ethnicity	Mixed ethnicity
School average	7.6	6.3	6.3	6.3
Class				
Class year	2nd (B)	2nd (B)	2nd (B)	3rd (B)
Gender	9f/20m	10 f/14m	8f/21m	10f/8m
Labwork				
Topic	States of matter	Classical mechanics	Radioactivity	Radioactivity
Labwork	Ideal gas law	Conservation of mechanical energy on air track	Half-width and half-time	Half-time and half-width
Available time	2 times 90 minutes	45 minutes	90 minutes pr. labwork	90 minutes pr. labwork
Students				
Group 1	Abby and Abraham	Bridget, Brianna and Brit	Carrie, Camilla, Carl, Cam and Carolyn	Daisy, Dana and David
Group 2	Anita and Annie	Bob, Bonnie and Bobbi		

question - actually the opposite. If these didactic-engaged teachers are having issues figuring out their intended learning outcomes for labwork tasks, it is reasonable that less didactic-engaged teachers are having the same problems. Also, for the case of the experimental cases, it showed to be important that the teacher understood and wanted to engage in the study design in order to gain reliable results.

In the following the data concerning the case teachers are investigated in order to clarify their intended learning outcomes of their individual labwork activities as well as the declaration levels of these intended learning outcomes. The data investigated are the interviews with the teachers, their labguides as well as their introductions to their labwork activities to the students.

The presentation of the data is chosen to be done in a systematic comparison of the four in-depth data collections, such that e.g. each labguide is compared before moving on to the introductions. In that way it becomes easy to compare the ideas and choices of each of the case teachers. On the other hand, the story of each individual teacher and his/her labwork will be split up. It is hoped - based on the small amount of cases - that this will not blur the picture too much.

4.3 Teacher interviews

In this section the data from the introductory teacher interviews at the four in-depth data collections (Alice, Burt, Charles and Derek) are found. The interview guide for these interviews was the same, and can be found in appendix B. The interviews were run in a semi-structured way (Kvale 1997), giving room for letting the interview evolve in interesting ways, but still picking up on all initially decided themes.

In the following, three questions are investigated:

1. Why should labwork activities be part of the teaching physics in the Gymnasium?
2. For the specific labwork activity to be investigated, what is the intended learning outcome?
3. Why have you chosen to run this labwork activity as a guided labwork?[1]

These questions were not posed to the teachers in such a direct way, and are therefore extracted from various parts of the interviews. After having shown excerpts from each of the teachers' interviews for each question, a discussion of their answers, a comparison and some reflections on their reasons for answering the way they do is given.

4.3.1 What to learn from labwork activities generally?

In this subsection transcripts of the introductory teacher interviews related to the teachers' views on labwork generally are displayed, showing how the teachers discuss the role and function of labwork activities in the physics teaching.

[1] The questions *What should Gymnasium students learn at their physics classes?*, *How has the design of this particular labwork activity evolved?*, and *Will the students be aware of the intended learning outcome of the specific labwork activity?* are investigated in appendix C.

Alice - what to learn from labwork activities generally?

Alice discuss the purpose of labwork activities in a number of ways.

First she discuss purposes related to theory:

156 **Alice** Well, they are to be used both to illustrate and give understanding to the
157 theory, it is very important. It is a way of working with the content. Like
158 solving a task, that is also a way of working with it. It gives insight and
159 understanding. [. . .]
162 **Alice** But it is often based on the fact that you have some theory and then you
163 go out and do an experiment and the experiment then gives rise to new
164 questions, and then you go back to theory and tries to find something
165 there to explain what you have seen. So it is an interaction. [. . .]

Alice perceive labwork activities as having an importance through providing students with illustrations and understandings of the physical theories in play. She also underlines the importance of the interplay between theory and experiment.

Alice continues on by talking about motivation.

167 **Alice** But I remember that my own attitude towards labwork activities when
168 I was in the Gymnasium was very negative, really negative. I thought it
169 was quite silly; it was a waste of time. It was just. . . you took the labguide
170 and it said ‘do this, do this, do this’. And then you did it and then wrote
171 a report and it had to contain these specific things, and by the way the
172 real job was to copy the teacher’s labguide, we should just reformulate the
173 text. And I hated it.

174 **LBJ** I wonder why.

175 **Alice** I did some evaluations with my students and asked them about it. The
176 first time I did it I expected them to feel the same way as I did, but
177 they didn’t. At all. And that was really very positive, but I was very
178 surprised, I really was. They thought it was a nice variety; that was what
179 most answered - that it was a variety to the normal teaching. And they
180 thought it was educational, but the most educational was not in the class,
181 because it was not always they could understand what happened during
182 the labwork. But returning home and doing the report, there they really
183 learned something. They hated writing the report, but they learned a lot
184 from it.

Finally, Alice states, the purpose of labwork activities is to give the students a possibility to intensively work with a physical task through the report writing.

Burt - what to learn from labwork activities generally?

Burt states his views of labwork as an educational activity in the following way:

90 **Burt** It gives them the sense of what physics is and how one works with physics,
91 and where the results of physics come from. So it is also about the scientific

92 method, empirical data and development of theory from the data and so
93 on. But they are not to do too much of it themselves.
106 **LBJ** Then what about labwork activities in relation to what we just talked
107 about?
108 **Burt** One could say that on the lowest level [in 1st year of Gymnasium where
109 physics is mandatory] it probably does not mean that much. Because it is
110 not people who will continue with their education in this direction. But
111 it still has importance, because it is the way one works with physics. It is
112 where the results come from. And I think it is very good to have it in your
113 own hands. When reaching a somewhat higher level, where one chooses it.
114 And it is not like one can not learn physics without it. E.g. my first year
115 at university was totally without labwork. It is absolutely possible; but
116 the discipline will be poorer without it. And in several ways. For once it
117 is more difficult to understand what physics is, and why physicists work
118 like they do. And for second the experiments are also a way of learning
119 things. Well to read and calculate, that is fine, but there is also another
120 way of maybe reaching the same content. And it is not necessarily making
121 it easier, because when you both have the theoretical and the experimental
122 then it is often difficult to make it all come together. So it is also a way
123 of getting into the concept in a deeper way.
124 **LBJ** So one can teach physics without labwork, but you will not like it?
125 **Burt** One could teach completely without labwork, but I wouldn't recommend
126 it.

Later, when we talked about this last saying again, he told me it is like the English teacher can show movies in class to make a variety in the teaching activities, but for labwork activities it is even better since the students are actively participating.

Burt tells in the transcripts above, that laboratory work is a way to give students an epistemological understanding of physics; what physics is, how to do physics, where physical results come from etc. This he relates to the scientific method. This is though not something he expects the students to be able to do, to work after scientific methods. But they should be presented to it. Then he continues to talk about laboratory work as a means for learning conceptual/theoretical ideas of physics, and that theory and experiments are two different ways of thinking for the students, and therefore is difficult, but is a possible means for a deeper understanding. Finally he says physics can be taught without laboratory work, but it has a value as a variety.

Charles - what to learn from labwork activities generally?

Charles states his views of labwork as an educational activity in the following way:

182 **Charles** Since the purpose of it [labwork activities] is they have to go to the
183 exam, the experimental exam where they have to do an oral report. Be-
184 sides that there is no purpose of them doing reports all the time.

Having searched through the transcript of the interview several times, it is not possible to find a place where he talks about the labwork activities for having other reasons then to possibly upcoming exam.

Derek - what to learn from labwork activities generally?

Derek starts by stating the difference between labwork activities in the research discipline of physics and the school discipline of physics:

42 **Derek** Because there is a large difference between doing experimental work at
43 universities and in research, and its role in the Gymnasium. Partly because
44 the disciplines are not the same. Physics in the Gymnasium is far from the
45 same as at universities. So there is a fundamental difference. Also because
46 you can use labwork activities in the Gymnasium in many different ways.
47 There exists many different purposes of doing labwork activities, whereas
48 on the university level and at the research level, there do not exists so
49 many purposes.

Then Derek starts listing a number of purposes with labwork activities, where the first is the variety from other forms of teaching.

58 **Derek** One is that they do something, simply. They don't sit down being pas-
59 sive. And it is a pretty nice thing to do occasionally. So this thing about
60 activating the students, it is always good no matter what tricks you use.

The second purpose is to teach theory, which he divides into two:

61 **Derek** Then some hold the idea - well, now I say 'some' since I do not subscribe
62 too much to this idea - that it can be a review of the theory you are to
63 learn. So if I were to learn about the conservation of energy then I do some
64 experiments with energy conservation, so you can all see for yourself, and
65 it is very pedagogical some say. [...]
81 **Derek** But at the same time I think you have the obligation to somehow show
82 that what is written in the books or in the teaching materials are actually
83 related to the things that occur in the laboratory or in nature. We can
84 observe it and measure it. So I think you owe it to show them that what we
85 talk about is not abstract and of another world. We talk about something
86 which we can see: 'just look'.

The first is to convince students of the truthfulness of the presented theories (which Derek does not completely believe in as a purpose for labwork activities), and the latter is to convince students that theories are related to and springs from nature.

The third purpose, he presents, is related to the nature of physics:

Derek A third thought concerning labwork is to say, that it is something very special for the discipline of physics - almost an independent thing. Of course you use theory when doing labwork activities, theories are in interplay. But the purpose of doing labwork activities is to give students an understanding of a certain way of investigating some areas of nature. In physics we can actually address nature in a very unique way, which is worth learning. It is a purpose in itself to do labwork activities.

Derek's third argument concerns the nature of physics, and labwork's role in this.

The fourth purpose is related to formation and testing of hypotheses:

Derek Which hypotheses can one propose? How do you propose reasonable hypotheses? How can you practically make sure you can test or investigate your hypotheses? How can you make a setup with nature to investigate these hypotheses?

Fifth, he states:

Derek How do you do it systematically? How do you make sure you are stringent? How to avoid placing gum the wrong places etc? Or how to make sure the length is the same every time? There is also some systematic in it. To have a sense of factors and variables, and you can't have too many balls in the air at the same time. You control only one variable at a time. So there are a lot of things to train here.

Here he talks about procedural skills related to doing labwork activities, as well as understanding the inquiry processes of physics.

Finally, Derek talks about the data treatment and the mathematical part of doing labwork activities:

Derek And besides all of this, there is an entirely different part of it, and it is the handling of the produced data. And it gives quite a hassle, because it is primarily concerned with mathematics. They like to do experiments, but when they are to treat the data they find it boring or difficult, because it demands mathematics. And it does not come easy. But that part is also quite important, to evaluate and handle data.

He outlines how labwork activities is a good entrance to engaging the students to do the mathematical data handling, since his experience is the students are not liking it and are finding it difficult.

Comparison - what to learn from labwork activities generally?

Having now presented the four case teachers' view on labwork activities in physics generally, their perception of their specific labwork activities are to be presented. But first an overview is given at table 4.1.

As it is found, all four teachers talk about the practical reasons for doing labwork activities, though in a different way: Alice, Burt and Derek talk about

Table 4.1 Comparison of the case teachers' view on the general purposes of labwork activities in physics at the Danish Gymnasium.

Teacher	*General purpose*
Alice	Illustrate and understand theory
	Display the iteration between theory and experimental data
	Affective reasons
	Intensive work with physics tasks through the report writing
Burt	Epistemological reasons
	Alternative way to engage in physics
	Learning theoretical physics
	Linking theory and practice
Charles	Experimental exam
Derek	Alternative way to engage in physics
	Learning theoretical physics:
	Arguments for rightness of theory (questions argument)
	Arguments for relation between theory and nature
	Epistemological reasons
	Learning hypotheses making
	Learning labwork related procedural understandings and skills
	Engagement in data treatment and the mathematical side of it

labwork as a variety from other ways of working with physics; and Charles talks about the upcoming exam. Alice, Burt and Derek also talk about learning theory and learning about the nature of science through labwork activities. Derek unfolds his arguments to a larger extent than the other teachers, possibly based on his background in physics education research which have given him insight into research literature concerning categorizations of purposes of various activities in physics classes.

4.3.2 What to learn from this specific labwork?

Here transcripts concerning the reasons and intended learning outcomes of the teachers' specific labwork activities are discussed.

Alice - what to learn from this specific labwork?

Alice first explains how the specific labwork concerning the ideal gas law was developed, and how she came to centre the labwork around the control of variables:

Alice And it was actually only last year I came up with this variable control thing, and I have actually always assumed, yes, but of course it is obvious that you can't vary several things at the same time.[. . .]

228 **Alice** And lead them do it themselves, yes what is it to keep constant and what
229 is to be varied. And it gave a much better understanding of the labwork,
230 I think it actually worked, and I decided to use it again.

After having outlined her concept of control of variables, she continues with her second intended learning outcome:

266 **Alice** And one of the things I would really like, and which I have told them
267 about before - it is not the first time they are doing a graph - it is when
268 they reach a tendency equation, $y = 0.573x+17$, then I would really, really
269 like them to translate it so it said $p = 0.573\ldots$ and then a unit afterwards,
270 and then write times this quantity there. I would like them not to write
271 x and y, and I would like them to write units on the quantities. And it
272 appears to be difficult.[...]
293 **Alice** It is so easy here, because well a first you cannot measure n, but you
294 see what the volume is at room temperature and barometric pressure,
295 and then you have the first part, the introductory labwork, which shows
296 how much space one mole takes up, then you can calculate the other way
297 around and find out how many moles you got when taking $50mL$. And
298 the graph does not show that, well it is something they have to do. And
299 then measure, measure the pressure in, I do not know what it measures
300 in, Pascal or something. And the temperature in Celsius and the theory
301 demands it to be in Kelvin and the volume is in millimetre and it has to
302 be in cubic metres in SI-units, so there is a lot of conversion of units. And
303 it is really good for them, because they bungle in it.

In this excerpt Alice explains her intended learning outcome related to the translation between data as displayed in a graph on a strictly mathematical form, and translating it into 'physics' by changing the fit function to a function of the present quantities with the proper units. And she explains how she has experiences this to be quite difficult for the students.

She ends out by summing up:

322 **Alice** Well, the goal of this is first and foremost that thing with learning about
323 control of variables. And then to train graphical treatment of the data,
324 which we already have done a lot. And then of course to be familiar with
325 the equation of state. It is kind of atypical, maybe in the sense that I am
326 so aware of the thing with variable control. Because the other labwork
327 activities has been more about working with the core content, where it
328 does not have a, what to call it, a meta-cognitive goal, like this one has. I
329 wish to be honest; it is not like that every time.

So what Alice says here is that her purposes of this task it to give the students an understanding of fair tests (which she calls variable control). This fair test is to be understood as in ordre to gain knowledge of the dependence of a variable to another, it is important (and sometimes difficult) to keep all other variables constant. Besides this she wishes her students to be able to 'translate' a graph and appertaining fit equation back and forth between mathematics and physics, where the mathematical equation typically would be of the form $y = 0.537x+4.2$ and the physical equation would be of the form $p = 0.537Pa/mole \cdot n + 4.2Pa$. From this the students should be able to extract most possible knowledge of the experiment before comparing it to theory. This she names 'to be systematic'. Both the translation and the systematization are according to Alice's experience very difficult for students at this level. And finally she wishes the students to be familiar with the equation of state. But this more or less comes as a passing remark in her summery, and it is definitely not the main focus of this labwork.

It has meant a lot for the development of this dissertation how she explains her intended learning outcomes of the specific labwork. Both that she does it, but also how she explains the difficulty she had in being aware of both this way of thinking about labwork activities, but also to be able to develop her intended learning outcomes for the labwork. As will be shown in the following two transcripts from Burt and Charles, this is not something every teacher is aware of.

Burt - what to learn from this specific labwork?

For Burt it seems less important to explain the reasons and rationales for the specific labwork, and he seems to wish to talk about the entire sequence of modules concerning classical mechanics. He, though, states some purposes, starting with the concept of theory building:

Burt Then there is some of the things that are slightly beyond the things which are precisely within the topic, which I also want to include. And that is the thing with theory building, well, most often you start with something you can observe or measure, and then that is the ground. And for this labwork it is not really like that. Here it is the term of work, which we start out with. How to define it in a proper way? Then you can start by doing small measurements thereafter to illustrate it. But it is not emerging from observations. And then how can you build a theory from that? And maybe understand - not maybe - hopefully understand some of the things they have been through, on a higher and more systematic level.

Here Burt talks about presenting students with different examples of how physical theories are being build and adapted historically. For the case of theories within classical mechanics concerning energy (kinetic, potential and mechanical), this concept did not emerge out of experiments, but is a pure theoretical construct, which when (defined in the most appropriate way) showed useful in theory as well as experimentally.

He continues with the arguments beyond the actual topic by talking about the concept of conservation:

488 **Burt** Another thing which is central in physics on a more advanced level is the
489 thing with the laws of conservation.[...]

He continues from this excerpt by listing various places in physics, where conservation plays a huge role, e.g. charge, momentum, leptons, within radioactivity etc. He wants to use the concept of conservation of mechanical energy as a stepping stone towards the general concept of conservation, which is to be met a number of times in the physics education of the Gymnasium.

He finishes by talking about the scientific methods:

513 **Burt** And then in a somewhat scientific way to work with physics. Not just
514 phenomena to phenomena, or topic to topic. But really across the disci-
515 pline.

He deliberately talks about this, as not he way of working with conservation of mechanical energy, but the way of working with physics, which could be exemplified by working with conservation of mechanical energy along with all other topics within the curriculum.

Charles - what to learn from this specific labwork?

In the interview with Charles, he talked about the intended learning outcomes of both the module and the two labwork activities (halftime and halfwidth).

He starts out by stating the importance of the concept of probability:

392 **Charles** Calculation of probability, well to say something has a probability. I
393 do not think a lot of people have an understanding of it. As seen from the
394 lessons, the students have not been working a lot with probability before,
395 and it is known how this concept is difficult to grasp. I don't think so. And
396 when talking about probability, naturally I will say the law of radioactive
397 decay.

He talks about how students normally have difficulties by understanding this concept of probability and how this naturally leads on to discussing the laws of radioactive decays.

He then continues with an argument within general education, talking about radioactivity and society:

396 **Charles** It is not so much that they have to learn about alpha, beta and gamma,
397 but more like, what I call, how harmful it is. Not because a power plant
398 blows up every day, that is not why. Especially because we have Chernobyl
399 and maybe others in the future. Damn, I don't know. But I fell they can
400 use it in their daily life in the future. Well, should I run away if alpha is
401 hitting me, or should I run away if it is gamma that hits me? And what
402 is the difference between the two. Etc. And that is what I mean they
403 can use in the future. And that is what I want to give them. Namely,
404 probability, you know that there is a probability, and then how harmful it
405 is. It is like what I want them to leave with. Well.

When questioning his points of doing halfwidth and halftime in connection to the harmfulness of radioactivity, he states:

LBJ Is it what you specifically want them to learn from the labwork about halfwidth?
Charles Yes, yes, which one of the kind that penetrates. . .
LBJ What kind of room to enter [laughs].
Charles Precisely, e.g. how to protect yourself. And when to come out, and that is why we take Barium when talking about halftimes.
LBJ [Laughs]It is kind of looked for, isn't it?
Charles Yes, yes, that is how it is. When to get out of the room? Yes, it takes 10.5 million years, when it is Uranium. That is how it is. Well. And that is also why you talk about places on the Earth which is inhabitable due to a high level of radioactivity, yes. Something still decays, and then you have the halftime. And you might hear it will take 3,000 years. But why does it take that long? Well, that is what I am saying. But it is our task to tell about the concept of halftime, and that is why it takes 3,000 years, because then half of the material has decayed. Or you can expect after 3,000 years that very little is left, even though in reality it will never disappear, since you have the exponential function, etc. Well.

He sums up by saying, when asked which competencies the labwork activities train:

Charles Yes, shut up. Eh, what have I thought of? All sorts of things. Yes, I God damn don't know. But it is like I say. I think I put emphasis on the data treatment again. When they are measuring something, then it has to be typed into excel, and then they have to see how things relate, and then of course they have to use it, and not just throw it away. But it is of course also to get a sense of what we talked about before. What can I use it for on a longer timescale? Yes. If a power plant blows up, do I run into an aluminium house, a paper house or a lead house, and how long should I stay in there, before leaving again.

He summarizes by placing emphasis on learning how to do handle data and to be able to relate radioactivity with societal issues.

Derek - what to learn from this specific labwork?

Due to the experimental approach, where I have engaged actively in planning of the labwork and the presentation of it before this interview, we do not discuss the specific intentions with the two labwork activities, since this has already been established beforehand.

Table 4.2 Comparison of the case teachers' view on the purposes of their specific labwork.

Teacher	*General purpose*
Alice	Fair test (control of variables)
	Graphical data treatment (translating between math and physics)
	Familiarization with the equation of state
Burt	Theory building
	Concept of conservation
	Scientific method
Charles	Handling of data
	Concept of probability
	Harmfulness of radioactivity

Comparison - what to learn from this specific labwork?

Again the findings from the teacher interviews are summarized and compared, now in relation to the question of the teachers' purposes for the specific labwork in play, see table 4.2.

Alice is very well aware and articulated about her intended learning outcomes of the specific labwork activity, giving a threefold purpose of fair test (control of variables), graphical data treatment (translating equations between 'mathematics'' and 'physics'), and familiarization with the equation of state. Alice even placed the intended learning outcomes in a hierarchy, where the fair test comes first, and the familiarization of the equation of state is the least important, as this will be discussed in non-labwork classroom activities. She also explains how difficult it is to gain the understanding of the learning outcomes, which could be used to explain a labwork. The labwork activity itself comes before the arguments for it.

Burt also puts forward several intended learning outcomes for the specific labwork, though it seems he to a higher extent than Alice made it up along the interview. Since that is not easily judged, his way of presenting the labwork orally and in writing in the labguide must show this. His intended learning outcomes are then theory building, the concept of conservation, and the scientific method. Burt does not place a hierarchy on the intended learning outcomes, and it is not totally clear from the interview transcript when he talks about the labwork activity, and when he talks about other activities within the sequence of modules in the topic of classical mechanics.

Charles put forward three intended learning outcomes, but from this interview transcript, it is very clear how this is something he is considering along the way. His intended learning outcomes can be listed as concept of probability, harmfulness of radioactivity, and handling of data. Based on his statements, he place most emphasis on the third reason, since this has the largest value in relation both to the upcoming exam, and to the students further studies and carriers. The argument of harmfulness seems slightly silly, continuing to talk about paper vs. aluminium houses etc. but it seems he takes the argument serious himself.

As seen all teachers have very different arguments for running their specific pieces of labwork, which is also to be expected from the different nature of the labwork activities.

More interesting is it to notice to which extent they have considered this before this interview. In the interview with Alice, it is very obvious she has given these questions a lot of consideration, and she puts if forward with no hesitation. From the interview excerpts you would expect the arguments to be present in the design of the labwork task. For the case of Burt, it is less obvious whether this is made up along the way during the interview, or it has been considered beforehand and therefore whether it will be present in the design and execution of the labwork activity. For the sake of Charles, it is very obvious how he makes up his arguments along the way, and it is not expected the intended learning outcomes will be thought into the design of the labwork. For this reason it seemed Charles was the perfect case for the experimental study, since it should be possible to make him follow the research design (of two labwork activities with high and low declaration levels, respectively), without having him compromise his own teaching strategies. As will be explained in section 4.5.3, this plan did not go completely as planned.

4.3.3 Why do guided labwork activities?

All four teachers run their labwork activities as guided in the sense they hand out labguides which the students are to follow with clear cut instructions on which data to collect, how to collect them, and what to do with them afterwards. When following the labguides it should be possible to do the labwork without much or any preparation before entering the school laboratory. All four teachers were asked in the introductory interviews which thoughts they have about this way of doing labwork activities; reasons, pros and cons. In the following transcripts they explain their arguments.

Alice - why do guided labwork activities?

First Alice explains why completely free tasks are not a possible option in the Gymnasium:

Alice Well, you do not get the ideas without knowing which possibilities there exist; as a matter of fact I find it very difficult if you do not have any ideas of what can be measured. And this is why some times, when we want to

201 leave it to the students to make up something, it is . . . totally blank. And
202 the reason why they are totally blank is maybe not that weird because
203 how do you make up something, if you do not know what can be measured.
204 And there is always something, which is impossible to measure.

Alice here explains how students are not aware of what is possible and what is interesting to investigate experimentally, and expecting them to be able to do that without any guidance is quite naive.

It was then asked to which extent the labguide includes a level of freedom in the labwork, and she explains how this is not the case:

236 **LBJ** So they have some freedom to choose how they will manage this task?
237 **Alice** No, not that much.

Here Alice explains how she has earlier on tried out freer and more open tasks in the laboratory:

632 **Alice** I have tried different things, and I must admit it works best with the more
633 closed labwork activities. Well, I hope with this class to let them on the
634 loose. But I have learned it is not something one can do just like that.
635 Because I have tried, and I was deeply disappointed that it did not work,
636 and the students did not like it. At all. It was no success. I had been
637 at this in-service course and heard how good it was with all these open
638 things, and it simply did not work.

Bear notice to the premises on which Alice judge the success of a given task, namely to which extent they do what she expected them to do, and to which extent the students liked the task. She does not mention whether they learned what she intended. It could though in her terminology be included in her phrase of 'it did not work'.

Burt - why do guided labwork activities?

Burt also explains how he has been trying out different degrees of guidedness at the laboratory:

239 **Burt** Very often the regular labwork activities are very closed, what used to be
240 called cookbook exercises. Where they are told precisely what to do, and
241 more or less what to expect. And I think it is totally fine as a part of it.
242 Some times it is more open-ended, where they are first told to examine
243 something and are told precisely what to do, and then make a similar
244 exercise on something slightly different, and then they have to design the
245 measuring program themselves. But for the normal labwork activities it is
246 normally quite closed. And I think it is fine as long as there are also some
247 sequences where they are asked to consider what to investigate to a higher
248 extent. What to measure, how to plan it. Not from scratch, because then
249 they get nowhere, but anyway.

Burt has experiences with very open labwork activities, where - in his words - the students get nowhere. He has more positive experiences when running the labwork activities as first a completely guided labwork and thereafter doing more or less the same thing now with the students designing the measuring program. For the latter task, he outlines how the students then are to consider what to investigate to a higher extent.

Burt is also talking about the effectiveness of the guided labwork activities:

Burt But it is also important that it works while they are at it. They cannot meet unprepared and spend all of the time thinking. Then it is better to get the job done and think afterwards. But you have to have thought about it beforehand and during, also to see if the results are reasonable. Well, you have to be able to detect the errors you are making. Errors in the measurements.

When doing guided labwork activities Burt is sure all students will get the job done, and by the job he means to get the needed data collected and some first estimates of the validity of the results. This on the other hand leave the possibility of the students doing the labwork activities without having any clue of what they are doing, and all thinking is left to the time of the report writing. And Burt thinks this is fine; since the class time should be spend on the collection of data, since this is the only thing which cannot be done at home.

Charles - why do guided labwork activities?

At first Charles explains how other teachers fancy doing long and thorough labguides:

Charles And then there is some [other teachers] which love to do very thorough labguides for the students.

LBJ Then it can't go wrong.

Charles Right. Well, that is it, it simply can't go wrong. And in other word, it is ridiculous to do the report afterwards. Because you used to when doing the labguide, to write precisely what the purpose of the labwork is, to tell it to the student. But the intention is also for the report writing to have a purpose. But the labguide typically contains theory, which equations to use, and what the theory is behind it. And the student also have to write this in the report. It should also contain the apparatus, the labguide, and the same thing with the report, which the students are to hand in. So in other words, the students can do the most, more than half of the report by copy-paste from the labguide I give to him. So the only thing he has to do, that is two things: it is the data treatment and the conclusion in the end. And that is no good.

Charles has low thoughts of these kind of labguides, since the students are served most of the lab report on a silver plate, and he find it foolish for students purely to rephrase the teacher's words of the labguide.

When Charles does labwork with his students, he explains he either gives them labguides and clearly tells them just to work on the handling of data and the conclusion and copy the rest:

367 **Charles** That is why I say, if I am to give them a labguide, well, then I tell
368 them directly, well this is written in the section of the purpose and the
369 theory, and I have written it to you, so please just make a copy and put it
370 in the report, then I will focus when grading it, of course on the handling
371 of data.

Alternative he does not give them any labguide, but has just made sure everybody knows how to write up a report by giving general guidelines for lab report writing:

371 **Charles** If you don't get a labguide, well, then you do it all from the top, and
372 that is when I think the learn the best, if they have been given some
373 guidance on how to write a report, and I have given them that. Then it
374 is the students who write the report. And then I don't bother doing a
375 labguide. I don't really feel they are learning anything. Of course it is
376 nice when it says 'plug that in there and that in there' etc. Yes. But it is
377 not like they are dying if they do something wrong.

Charles argues why he does not prefer guided labwork activities, since the report writing of guided labwork activities does not really have a purpose, it is just copy-paste. Therefore he either chooses to give the students labguides and ask them purely to focus on the handling of data and the conclusion. Or even better to not give them a labguide and then let them on the loose, which he expect cannot go completely wrong, as long the labwork equipment is safe to use. And this is the case where the students learn the most.

As will be shown in the following, the labwork activities he presents to the students are strongly guided.

Derek - why do guided labwork activities?

Derek discusses how his choice of the type of labwork is related to his purpose of the labwork.

113 **Derek** Yes, of course, it is evident that if you use it as motivation or other
114 things, like theory support, then it is in a genre of its own. If you want to
115 give the students an understanding of what it means to address something
116 experimentally, to test reality - when you do physics, then obviously there
117 are so many balls in the air that the students will not be able to handle
118 it. It is too difficult to keep track of everything at the same time. So
119 no, it would be difficult [to do labwork activities for a large number of
120 purposes at the same time]. And then it would typically be - if you look at
121 standard labwork activities [guided pieces of labwork] - that you downplay

the students' design part of the labwork, and putting forward hypotheses you also downplay. You also downplay what the purpose is, and then you use all the energy on . . . then you help them forwards, hold their hands, till they have the data. And then you can let go. So what you place emphasis on is to get theses data treated mathematically. That is the most typical. And that is fairly reasonable excepts - because it is so difficult to do the mathematical data treatment - if you do not supplement it occasionally with a focus on other elements of the experimental work, then of course they will not learn it, and then they loose a lot of important knowledge, e.g. to plan experiments to investigate this hypotheses. These two things are important, but the knowledge will not come by itself. And then you should focus, so to say, that when we have the data, then maybe it is not important what the data has to say, or, yes, it is not the point of the present task.

As Derek says, he uses guided pieces of labwork for most labwork activities, because he often places emphasis on the handling of data, wherefore it is important they gain the data to be handled. If the aim is to gain data for data handling, then it is needed to guide the work, else the students will not be sure to gain the relevant data, simply because the task would be too difficult. Occasionally, Derek explains, he does other types of labwork activities, where the purpose is different, e.g. hypotheses making and labwork designing.

Derek But it, it needs, what you do has to be very simple, and the simplicity bothers you a little, because then you will not gain the theory-purpose into the labwork, the core content would typically not be presented. And it lays somewhere in the reptile brain that it has to be related to the theory, it is not enough with the method, there has to be some content in it. And therefore you maybe pace it further than needed, also because the students are not used to it, which cause them to ask many questions, and it makes it difficult. But so is math and that you train a lot. So I think it is possible. But you have to take small steps.

In the second to last sentence he reveals that he has not actually done these types of purpose-driven labwork activities, but only wishes to do so.

Comparison - why do guided labwork activities?

Alice's reason for doing guided laboratory work activities is based on her own experiments on giving students less guided tasks. Her experience tells her the students are not approving of the tasks, but also they do not live up to her expectations, since the students are not doing what she expected them to do with the task. Therefore she has returned to the guided labwork activities, in which she knows the students will be satisfied and be able to handle the task.

Burt uses guided labwork activities most often, since these are quite effective in getting the students to gain the required data within the time slot dedicated for the labwork activity. Within this period the students should be able to collect the data and estimate the validity of the data, and in case of untrustworthy data the data series can be redone. He, though, does not expect all students to grasp the task while doing it; the thinking is left for the report writing, and he does not feel bad about this.

Charles prefers not even to write a labguide. When talking about it, he likes to make it sound like this is the most normal way of working in the lab for Charles. But somehow it seems he has not tried it out, since he is only talking about the possible problems of students plugging in the cords wrong, and never talks about whether the students like it, are able to set up a measuring design, are able to get anything measured, etc., such as Alice was talking about. He spend a long time in the interview explaining to me the silliness of guided labwork activities, where students are copying the theory and setup of the labguide onto the lab report, and the entire task can be done without much consideration. Still his own labguide shows his labwork activities are strongly guided. Charles is the only one talking about in which situation the students learn 'the best', where the other teachers talk about whether the students are able to get the job done.

Derek explains how labwork activities - where the aim is to gain the data for the mathematical handling - are most suited to be guided. Labwork activities holding other aims should be designed differently, but so far he has not executed his ideas. It the aim of a labwork is to develop hypotheses or design for testing the hypotheses, then the content of the labwork should most likely be downplayed to a level, where it at first sight seems unreasonable. But this is the deal, if the task should be possible to solve for the students.

All four teachers have chosen to do guided labwork activities. Alice and Burt have chosen this way of working with the school laboratory since it has shown to be very effective and the students seems to like it. None of them talk about the possible poor learning outcome of this way of doing the tasks. At least Alice must be aware of the possibility of poor learning outcomes, both based on her own experiences as a student, but also since she has been taken an in-service course about unbounded labwork tasks. Charles seems to be aware of the possible poor learning outcomes of the guided labwork activities, and therefore imagines how he is not doing guided labwork activities, even though he actually is. Derek uses labwork activities as a way to train students in the mathematical treatment of data, and he is aware of how guided labwork activities are the most effective way at gaining the needed data, but at the same time downplay the possibility of reaching other learning outcomes.

4.3.4 Summery of teacher interviews

As seen from the excerpts, the teachers' answers to the questions are quite different, but also their answering styles are quite diverse. First their answers - the similarities and differences - are summarized, and then some reflections of the interview situation are given, discussing the trustworthiness of their answers, the power distribution in the interview situation between the interviewer and the interviewee, and the teachers' rationales for answering like they do.

It is now summarized how the teachers talk about their specific labwork activities:

Alice is very aware of her intended learning outcomes of the task (control of variables, graphical data handling, familiarization of the equation of state), and she is able to articulate it very clearly. When talking about how her awareness of these intentions emerged and evolved, she explains it was not a trivial or easy task, and she had run the labwork activity a number of years before these reflections of the intended learning outcomes emerged. Until then the evaluation criteria are based on the students' like or dislike of the task and the number of obstacles they meet when doing the activity.

Burt seems to think about the specific labwork in a different way. Labwork activities for him are primarily a tool for varying his teaching, and therefore his intentions are centred on the students liking the labwork, being able to do the labwork, and seeing the theoretical concepts in a new light. Therefore his evaluation criterion is based on the number of obstacles the students meet during the labwork activity.

Charles seems to be using labwork as a training ground for the upcoming experimental exam. Therefore the important part of the labwork activity is to make the students be able to handle data, since this is in his view the most important evaluation criteria for the exam. Therefore the evaluation of the labwork is based on removing obstacles and providing further hints to make the students easily getting through the data collection, so they can get to the point of handling the data.

Derek is aware of the many arguments for labwork activities in schools, and has obviously been reflection on these both generally and in relation to his own teaching. When talking about his own practise, he primarily aims for gaining data for the data handling, wherefore he prefers to do guided labwork activities to make sure every student gains data to be handled.

Reflection on the interview situation

In all interview analysis, the interviewer/analyser should be critical towards the answers given in the interviews, and concern should be given to the interviewee's rationales for answering like they do.

In the previous the teachers' statements have been taken as true indications of their honest opinions. In the following two sections (section 4.4 and section 4.5) some of their statements - mostly concerning their intended learning outcomes of the specific labwork activity - will be triangled with their labguides and their introductions to the labwork for the class. Still something could be said about this state already now.

Rememeber the introductory quote at page 9, where a physics teacher questions the amount of didactical thoughts guiding the choices made in the design and execution of teaching/learning activities. He states: "...so if you wish to interview a representative group of people from the breed of physics teachers, many of them will - if you do not stop them in their venture - make up didactical reflections for the occasion."

It seems obvious from the interviews how this could most likely be the case of the interview by Charles, where he several times outburst things like: "Yes, shut up. Eh, what have I thought of? All sorts of things. Yes, I God damn don't know." to questions related to his intentions with the labwork activity. That should not be held against him, he is not lying in the interview situation, he has just not reflected upon these things to an extent where he can articulate them clearly in a sorted out way. Throughout the interview with Charles I several times felt we did not communicate very well, and how he often misinterpreted my questions and therefore answered in such a way I needed to rephrase the question a number of times, making him slightly annoyed with me. Maybe it was due to insecurity, which made him want to take over the interview. The interview was done on a limited time, and several of his statements seems rather rushed. Charles is centring his teaching on the upcoming exam, and he talks about the choices he makes in the light of this exam. I was very puzzled by this at first, but then we discussed his own educational background, and then I realized he had his first years of education in a Middle-East, where the rationales for teaching is not as centred on the idea of general education and to a higher extent focused on the results.

As opposed to Charles, Alice has clearly had a lot of considerations on the rationales for her teaching choices, and she is proud of the outcomes of her reflections. She supported her statements by e.g. showing me the first draft of the labguide during the interview, pointing to the description of her intended learning outcomes. This was the very first interview I did, and even though I felt comfortable in the interview situation, I was also very aware of my own inexperience. I can clearly see from the transcripts how I let her run the conversation, and it is clear what she wants to say in this interview. She is very well articulated, and she is able to e.g. list her goals and summarize them later in the interview without tripping. Even though I fell slightly manipulated, I find what she chooses to say in the interview to be very interesting and important, and therefore I was in no way disappointed by the interview.

Also Derek has obviously been given a lot of considerations towards the arguments for doing labwork in a school setting. This I expect to be an outcome of his background combining philosophy and physics as well as his PhD work in physics education research. His way of perceiving physics and himself as a physicist is different than the other teachers, since he places a large emphasis on the philosophical nature of physics and sees his two disciplines as combined. He does not define himself either as theoretician or an experimentalist, but more as a philosopher of physics, trying to place the physical knowledge we hold into a philosophical frame. This view of physics is seen in his discussions of school physics and school labwork activities. The interview situation was both very friendly and slightly awkward, since I know Derek as both a friend and colleague, and in the interview situation we were to play the role of teacher and interviewer. But after a few minutes, the role play became more natural, and we were making jokes along the way. I was quite aware of the answers I needed, but beside this I led Derek run the conversation as long as it fitted into the interview scheme. I was during the interview trying not to put answers into his mouth, which was somewhat difficult, since he had actively been participation in discussions of my PhD project as my colleague.

Somewhere in between Derek/Alice and Charles, Burt is placed. He is a very experienced teacher, and he knows what he is doing. He has spent a period of his career working with various projects for universities and the ministry of education, and is therefore obvious dedicated to having didactical thoughts. He just does not find it as crucial or worthwhile to the same kind of reflections of his intended learning outcomes of the labwork activities as Alice, since the labwork activities primarily for him is a situation for variation of the teaching styles, and he does not find labwork activities necessary for teaching physics either in the Gymnasium or at the university. In that sense it is obvious how his primary discipline is mathematics and not physics. I believe he makes up some of his didactical thoughts along the way, but he is also honest about that and some times tell me he has not considered this beforehand. I found the interview situation pleasant, but at the same time I felt he was kind of amused by my naivety - working hard to hide it. He was well articulated, and he took his times to answer my question, asking several times if I was satisfied with the answers he gave.

4.4 Labguides

So now the four teachers and their stands on labwork activities are known, and some understanding of the specific labwork activities their students are to do is gained. In this section the labguides of the four teachers are discussed.

At least two ways of analyzing the labguides can be done: the labguides can be analyzed for interpretation of the teachers' intentions with the labwork activity including analysis of the hints and obstacles imbedded in the task by the teacher (this type of analysis is found in the following), but the labguide can also be analyzed for investigating the physical content of the task, and thereby finding which potentials the labwork activities contain. From this analysis the potential learning outcomes can be extracted. Such kinds of analysis can be found in chapter 6 for a number of typical labwork activities held in the Danish Gymnasium classes. But for now the following is centred on the teachers' intended learning outcomes as these are explicitly or implicitly given in the labguides.

4.4.1 Alice's labguide

The case of Alice is naturalistic, meaning no influence on her labguide writing or other cases concerning the labwork planning and execution was done.

Alice is doing a labwork activity with the students in relation to the equation of state (the ideal gas law).

An English translation of Alice's labguide can be found at box D.1- D.7 in appendix D. Alice has herself formulated the labguide.

As she explains in her interview, Alice press forward three learning outcomes for this labwork activity:

1. control of variables;
2. graphical data treatment;
3. familiarization with the equation of state.

These three goals are each given a headline in the first two pages of the labguide, starting with 'Control of variables', by referring back to a labwork activity which the students did last year of finding the connection between the pressure and the temperature of trapped air. For this labwork, a description of which variables were kept constant and which were the independent and dependent variable are given, and why this is so. The next headline is 'Graphical data treatment', where the graph of last year's labwork results are shown with a fit equation $y = 34.6x + 94.5$, which is how it will be displayed by a data treatment software, e.g. Excel. This equation is below 'translated' into - what she calls - a physics equation of the form $p = 34.6\frac{kPa}{oC}\cdot t + 94.5kPa$, and thereafter translated to concerning Kelvin instead of degree Celsius, so $p = 34.6\frac{kPA}{K}\cdot T$. This leads on to the headline 'Comparison with the theory', where the equation of state is rewritten in the same form $p = \left(\frac{nR}{V}\right)\cdot T$, and underlining the importance of noting down the constant variables n and V to be able to compare the theoretical equation with the collected data.

Then the students are presented with a task for doing the same things, but this time for finding the connection between the pressure and the volume.

From here on follows a description of each of the four labwork activities:

- Determination of the molar volume of air (experiment 0)
- p as a function of V (experiment 1)
- p as a function of n (experiment 2)
- V as a function of T (experiment 3)

The first labwork is an introductory experiment to make the students able to find n by knowing the volume for the barometric pressure and the room temperature.

Each setup is described, and space is allocated for writing down the constant variables for each of the experiments.

The labguide finishes with a description of the demands for the report.

When reading the labguide by Alice, her in the interview presented intended learning outcomes are very explicit, each given a section headline. These purposes are naturally entangled, and she (deliberately) explains them by use of each other.

This labguide is unusually long (7 pages), where other teachers tend to keep it within one or two pages. But the labwork activity also contains four experiments.

The labguide is written to fulfil three different aims: to explain Alice's intended learning outcomes, to give the necessary guidance for the students to get through the labwork and receive usable data, and to guide the report writing.

4.4.2 Burt's labguide

The case of Burt is naturalistic, meaning no influence on his labguide writing or other cases concerning the labwork planning and execution was done.

Burt is doing a labwork related to the conservation of mechanical energy on an air track.

Burt has himself written the guide to the practical work. An English translation of the labguide can be found in box D.8- D.9 in appendix D.

At the interview with Burt he did not hold the same clear view of his intended learning outcomes of the labwork as Alice. Labwork activities are for Burt a variety of the teaching, and the teaching of physics could be done completely without labwork activities, though he would not recommend it. It is also a way to teach the methods of physics, the epistemology of physics and the theories of physics.

When analyzing the labguide, no explicit declaration of his intended learning outcomes are given, correlating with his statements in the interview. The labguide refers the aim of the labwork task to be 'investigate the transformation between potential and kinetic energy in movement on an air track'. The rest of the labguide is a guide on how to collect data, and an instruction on how to analyse the data and report the labwork.

When reading the labguide, it seems Burt's intentions with the labwork is to make sure the students gain the data needed for further analysis - and therefore the real purpose of the labwork is the following work of the data analysis and report writing. This fits nicely with his statements in the interview, where he talks about guided labwork activities as a possible non-thinking activity during the labwork activity itself. This, he states, is acceptable when the data analysis and report writing require engaged thinking activities (see page 83).

4.4.3 Charles's labguides

The intentions of the observation of Charles' labwork activities were to compare two cases, which were designed to differ by use of the experimental case approach. The plan was to test which impact it had on the students way of working with the labwork and their way of writing up reports, if they were previously been explicitly explained the intended learning outcome of the specific labwork. Therefore the first labwork (the halfwidth labwork, box D.11) was intended to be naturalistic, thereby functioning as a control experiment (since it was expected to have a low level of declaration). For the second labwork (the halftime labwork, box D.12) it was meant that Charles should present and make the students aware of intended learning outcomes of the labwork activity.

The two labwork activities were chosen, since they make use of almost the same equipment, are based in the same topic and are symmetric in the data analysis, and are therefore viewed ideal for the case of comparison.

First after the interview with Charles it was explained to him the intentions with the labwork activities (displaying the research design and instructing him on how it was planned he should introduce the two labwork activities). For the first labwork concerning the halfwidth of gamma rays through lead and/or aluminium, it was intended that he did exactly as he would normally do when writing a labguide and presenting a labwork. For the second labwork concerning the halftime of a Barium isotope, permission was granted to make changes to his labguide. Charles was given a written instruction of how the labwork could be introduced (see appendix D.10.

In the interview Charles explains the rationale for doing labwork activities as a school activity is all about teaching students to analyse data - which is again argued by its exam relevance. This argument closely resemblance Burt's argument and the structure of their labguides show the same pattern.

Charles' halfwidth labguide

For the case of the halfwidth labwork (which was not changed), the official aim of the labwork is 'To determine the halfwidth of lead and aluminium with a gamma source'. This is followed with an instruction to the data analysis (called 'Theory') and a guide to setting up and taking in data (called 'Setup').

When analyzing the labguide, Charles' intentions with the labwork seems to make sure the students gain the needed data for the data analysis. This shows that his intentions with the labwork are the work with the data analysis and report writing. This fits nicely with his statements of the general aim of doing labwork activities (see page 72), but it fits badly with his comments on guided labwork activities, where he explains how there is no point in doing labwork activities, if the labguide explains both how to set up and do the labwork, and how to do the data analysis (see page 83).

Charles' halftime labguide

For the case of the halftime labwork, an additional section in the labguide explaining the intended learning outcomes was implemented. The intended learning outcome for this labwork was chosen to be a focus on *random and systematic uncertainties*. The argument for this intended learning outcome is that radioactive decays contain random uncertainties, which is implemented in the theory the students have been introduced to before the labwork activity. Therefore the data are expected both from a theoretical as well an experimental point of view to alter from the theory in a random way. This can cause discussions of the usefulness of repeating the experiment and the possibility to increase the precision of the apparatus (which only can improve the results to the randomness of the radioactivity itself).

For the case of systematic errors this type of labwork also holds possibilities: The need for restarting the counter cause a time delay, which will systematically influence the time measures. Also the GM-tube holds potential systematic errors, since it is likely that a larger percentage of the gamma rays will go undetected for higher intensities than lower. This is discussed in further detain in part III.

The included section to the labguide is:

> This labwork task focuses on the ability to understand and work with *errors and uncertainties*, which are a general competence relevant both in and outside physics. In all earlier labwork tasks you have worked with errors and uncertainties, but you might not have given it thorough considerations.
>
> In physics you work with two types of errors: *random* and *systematic* errors: *Random errors* is an expression of uncertainties. These can occur by limited precision in the measuring devise. You know random errors when measuring the same quantity and reaching different results, even though you have not changed the conditions. Random errors can also occur by randomness in the system, like it is the case of radioactive decays, which you cannot predict when will happen. Since every measured quantity in physics is encumbered with uncertainties it is important to only state the result with the relevant number of significant digits (and possibly uncertainties if determined).
>
> *Systematic errors* are regular uncertainties in the system to be measured on, and the systematic errors change after a regular pattern, when the conditions

> of measuring are changed. You know systematic errors if you measure the same quantity repeatedly, and each time get a value below the expected table value. Then you have discussed which sources of error that could cause this smaller value, in other words which sources there exist for this systematic error.
> (Included section to labguide of halftime, translated from Danish to English)

The rest of the labguide is identical to Charles' original labguide. As for the case of the halfwidth labguide, this displays the aim as 'The purpose of this labwork task is to find the halftime of ${}^{137}_{56}Ba$', how to conduct the experiment in order to reach the relevant data, and a short comment on how to analyse the data. But the labguide has also included a section explaining the decay chain for Barium, which could possibly serve the aim of explaining the ion trading process used for 'creating' the radioactive Barium.

4.4.4 Derek's labguide

The research design for Derek is identical to the case of Charles; that is the intensions of observing Derek's labwork activities were to compare two cases, where as few factors beside the degree of declaration were changed, to test which impact the declaration level had on the students' work with the laboratory activities.

The choice of labwork is identical to Charles' labwork activities, namely halfwidth and halftime experiments. As opposed to Charles, the first labwork of Derek is the halftime, which is to have a very low level of declaration, and the second is the halfwidth, having a high level of declaration.

As explained before, for the case of Derek, he has actively been engaged in the development of my study, and therefore has agreed to 'play along' in a somewhat different way that Charles.

Derek's halftime labguide

For the case of the halftime labguide, Derek was asked to write a labguide, which (possibly to a lower extent than he would normally do) would not declare any intended learning outcomes. As a result, he wrote the labguide found in appendix D.13. The labguide has three headlines. The first is 'The aim of the experiment', and states 'We wish to determine the intensity of the background radiation I_{backgr} and determine the halftime of $Ba - 137*$'. The rest of this section explains how to isolate the Barium by use of the mini generator. This resembles closely the part in Charles' labguide. The second headline is named 'Background radiation' and explains the process of gaining an average number of background radiation pr. time. The final headline 'Main measurement' explains how to go through the process of gaining data, and how to do the data analysis.

Precisely as was the case of Charles, when analyzing the labguide, the intentions with the labwork seems to make sure the students gain the needed data for the data analysis. This shows that his intentions with the labwork are the work with the data analysis and report writing. This correlates very well with my intentions with the labguide. As seen in the transcript from Derek's interview dealing with the rationale behind labwork activities and especially guided labwork activities (see page 74 and 85, respectively), this does not go against how Derek would normally do labwork activities. As he highlights, this is the best way to do labwork activities, if the intention is to make students work with the data analysis, but this is not the only intention one could have for labwork activities, and should therefore be supplemented with other ways of working with it.

Derek's halfwidth labguide

For the second labguide concerning the halfwidth exercise, Derek did not want to implement the introduction I wrote for Charles. Instead he implemented a single line at the button of the labguide explaining the intentions of the labwork related to random and systematic uncertainties: *'Estimate and explain the random and systematic uncertainties of the experiment'*. This line is not intended to stand alone; Derek planned to spend some time talking about these two types of uncertainties with the class prior to the labwork.

For the case of the halfwidth, the arguments for emphasizing random and systematic uncertainties are almost identical to Charles' halftime labwork. For random uncertainties the same argument holds, namely both the randomness of radioactive decays, as existing in the theory, and the randomness existing in every measurement of a physical quantity. For the case of systematic errors this type of labwork also holds possibilities: If the measured width of the lead plates are systematically measured too large (or too small), then this cause a systematic error in the calculated halfwidth. Also the GM-tube holds potential systematic errors, since it is likely that a larger percentage of the gamma rays will go undetected for higher intensities than lower.

Else the labguide was (as intended) build up rather like the other labguide. First the labguide states: 'The purpose of the experiment is to determine the background radiation N_{backgr} and to determine the needed width of lead to half the γ-radiation from $Ba - 137*$'. This is followed by a guide to gaining the average level background radiation pr. time. After this, an instruction for gaining and analyzing the data is given. Finally, Derek included the line explaining his intentions in relation to uncertainties.

4.4.5 Labguide comparison

The labguides from the four different teachers are somewhat different, thought all serving the aim of making the students be able to get through the data collection process with a high possibility of gaining usable data for further analysis and a guide to this analysis process.

For the case of Alice's labguide, it has an explicit explanation of her intended learning outcomes for the labwork.

For the case of Burt, the labguide serves only the purpose of guiding the students through the processes of data collection, data analysis and report writing.

Both Alice's and Burt's design of labguides correlate completely with their stated intentions with the labwork activities.

For the case of Charles and Derek, their first labguides sole serve the purpose of guiding the students through the data collection, data analysis and report writing. Their second labguides serves the same purpose, but has an additional remark of the intended learning outcome of understanding random and systematic uncertainties.

4.5 Teacher introductions

So far the interviews with the teachers have shed light on their intentions with labwork activities, both generally and for the specific labwork activities. The labguide analysis shows nice correlations between their interview statements and the intentions more or less explicitly found in the labguides.

Now the teachers' introductions to the labwork need to be investigated to find the declaration degree, which could possibly be different from the level of declaration found in the labguides. All four teachers talked to the students about the labwork before letting them at the loose at the labwork equipment.

4.5.1 Alice's introduction

Alice started her introduction to the labwork in a lesson some days before the labwork activity was going to take place. After having briefly discussed the schedules for the different groups, she went straight into explaining her intended learning outcomes for this labwork activity, starting with her most important goal, namely what she calls control of variables:

Alice But this one has a slightly different goal than just to train the theory and what else there is of experimental things we used to have. It is special for this labwork that you should learn something called *control of variables.* It is something we are to use very much from now on. I will try to say it in a few words, or put it forward as a question, ssh... [writes on the board: 'What do you do when many quantities are variables?'] And for that the equation of state is really good..., there are a lot of variables. We haven't really looked at that before. That is the most important goal.

She does not really explain at this stage what she means with the term control of variables, but this is for setting the scene for the labwork activity.

She continues her introduction of her intended learning outcomes by naming the graphical treatment:

Alice There is quite a lot of graphs. Graphical data treatment. And that we have worked with for a while now, so to say. Let's call it further training. There will be three graphs in this report. There will be a lot of difficult things with units. For guaranty, oh, it is so healthy. To solve the puzzle. And it is really good for that, this labwork activity.

Again she is not very specific about what she means with graphical data treatment, but it is definitely to do with graphs and units. It seems also from her way of talking, that the students are aware of what she means with graphical data treatment. She continues by mentioning the equation of state:

Alice And the last thing is of course to be familiar with the equation of state. Like that. It is almost the least important part of it, because I don't think it is difficult to use it... take it in and calculate on it: oh, 'what is the volume then?' or 'what is the pressure then?' But it will automatically... It is the first two, especially the first, which you are to [her voice drowns in a cough from on of the students] as an example. And every time from now on when you do a labwork, then the first question to ask is, okay, which variables are you varying her, and which doesn't you?

This continues with a discussion of which variables there is in the equation of state, and the students easily lists the volume, the pressure, the temperature and the amount of matter. Abby, one of the students which is to be followed later, pose a question related to the equality of the variables.

Abby You can't vary, can you vary the pressure without varying...?

Alice You have to vary at least two things, when the things are connected. You can't only vary one without affecting the other.

Abby But if you want to vary the pressure don't you do it by changing either n or V or T?

Alice Yes, because they are connected.

Abby Then it is less variable than the others.

Alice No, I wouldn't say so, I could also change...

Abby If you want to change the volume then you have to change the volume. And if you are to change the number of nuclei [I expect she means amount of matter n when talking about number of nuclei], then you have to change the number of nuclei.

Alice Yes, and then you can say... What it is you are really doing, what sounds really... What you are really saying is what are we varying and what do we let be affected by the variation? And that is the pressure. Normally we vary these three [points at p, n and T], and then we wish to investigate

60 what happens with the pressure. But we are also to do an experiment,
61 where we vary the temperature and then investigate how it affects the
62 volume. That can also be done.

Abby only perceives the pressure as the possible measured quantity. Therefore she expect it to be 'less variable' than the other three quantities, since she cannot imagine an apparatus, that changes the pressure, such as she can imagine for both temperature, volume and amount of matter. Abby's point is very good since it shows her problems with inversion of equations. Her way of viewing equations is, that if y (in this case the pressure) is a function of x (in this case either n, V or T), then y will always be the dependent variable and x will be the independent. In physics (and most often in mathematics), if y is a function of x then there will in principle be an inverse function so x is a function of y, but Abby does not see this. Naturally this is related to control of variables, but not directly, and I expect Alice have not considered this in relation to her term of control of variables. But also because it shows how easy it is on transcripts to see what Abby is talking about, and how hard it is for the teacher to grasp it in the situation. Later Alice states:

88 **Alice** We can't only vary one thing, as Abby was talking about.

obviously indicating how she has misinterpreted Abby's concerns.

After this Alice gives an example of not having control of ones variables by showing the students two cases of measuring the pressure, and for the cases the volume, the temperature and the amount of matter are changes. For these cases it is not possible to determine which of the changed quantities caused the change of pressure.

Then Alice reminds the students of the labwork activity of measuring the pressure as a function of temperature, which the class did last year (results are shown at the first page of the labguide). She discusses with the class whether the amount of matter n and the volume V were kept constant in this exercise, and after some talk they agree upon them being controlled.

Thereafter she uses the same experiment to discuss which information can be withdrawn from the graph. Alice starts by making the students translate the fit equation $y = 34.6x + 94.5$ to physics, in other words to determine what physical quantity y, x, the slope and the b-value.

177 **Alice** And we have gotten this [points to the blackboard where the equation
178 $34.6x + 94.5$ is displayed], and now I would like to have it translated to
179 physics. And then we have to replace some things. And we should - now I
180 just check - this is measured in kilo Pascal and this is measured in degree
181 Celsius. So, if I replace x and y and put some units on, then what will it
182 look like?

This translation is partly done in relation to units. They are also discussing the value of b, which they agree upon should be zero (this was the argument for doing the labwork last year, where this exercise was to find indications of the absolute zero temperature).

From this introduction it should be quite clear to the students what Alice's intentions with the labwork activity is (understanding and being able to use variable control, be able to extract data from a graph by translating a fit equation to a physics equation and familiarization of the equation of state), and the intentions are overlapping very well with both what she told at the introductory interview and of those displayed in the labguide (which though downplays the importance of the graphical data treatment part described in the labguide, but is to take up most of the time in the data treatment and report writing). To compensate for the lack of description of the graphical treatment in the labguide she spends a lot of time discussing this in the introduction to the students.

From analyzing the labguide it might not be necessary to grasp the concept of the control of variables, since the design of the three main labwork activities described in the labguide has made it sure that two variables are kept constant, one is to be varied and the fourth is to be measured.

4.5.2 Burt's introduction

Burt introduced the labwork activity his module some days before the labwork was going to take place, approximately half a week before. He introduced the labwork concerning conservation of mechanical energy by initially explaining what the task is about:

Burt [. . .] is about mechanical energy, e.g. kinetic energy and potential energy. And we do it on an air track, we have seen such a thing before, but you have not been working for real with it yourselves.

He have in the lessons before been talking about mechanical, kinetic and potential energy in a more theoretical sense, and he is therefore expecting them to know the terms.

He then continues with explaining the apparatus: the functionality of the air track, the cart, the pulley, and how the air track needs to be horizontal. This is followed with a discussion of the kinetic and potential energy of the setup, and how these can be described by the equations of the theory.

Burt's final comment is on how the students should react to a situation, where the data does not fit to the theory:

Burt One with a minus, but else more or less the same [the value of the change in the kinetic versus potential energy]. And if it doesn't, then you have to make up an explanation for it. It will be okay, won't it?

The comment shows how Burt perceives labwork activities as teaching activities: The students are expected to find how the labwork resembles closely the theory, and if they for some reason do not, then the students have to come up with explanations for this difference, indicating the arguments are sloppiness or poor apparatus, and not issues with the theoretical model.

Burt then returns to the practical information about the setup and the labwork by explaining the importance of letting the cart start from the same position each time. This leads on to talking about the need for doing each measurements three times, and that each of the measurements should be more or less equal:

103 **Burt** So when doing this we are to do three measurements who hopefully are
104 identical, because then you can see at the measured time, is it more or
105 less the same each time, or else something has gone wrong. If something
106 has gone wrong then you discard the measurement. But when you have
107 three that are rather alike, then we use those and take the average.

He then talks about things which can be varied: the load weights, the pull weights and the length of the cart tab and the position of the photo cell.

Burt then explains how this labwork demands a lot of overview of the things to measure and be aware of and to help this he has written a scheme to make sure nothing is forgotten. This scheme also makes sure the students know how to calculate the needed quantities based on their measurements (see labguide in appendix D).

He finishes up with two remark, who can be interpreted as intended learning outcomes:

146 **Burt** So this one demands more calculations, but not more then you after all
147 will be able to manage, we try. [...]
149 **Burt** No, what it says here that has to be included in the report. And that is
150 it. Yes, shouldn't we just expect it all to work out? No questions?

Namely the training of calculating and the training of report writing.

Left is three aims for the labwork: getting to be able to operate the apparatus such as an air track and a photo cell with counter; training them into plugging numbers into pre-given equations (which does not necessitate considering the conceptual knowledge within these equations); and writing up a formal report.

4.5.3 Charles's introduction

Charles has - opposed to Alice and Burt - chosen to introduce the labwork at the very day the labwork activity. Charles was asked to explain the intentions with the second labwork (the half-time experiment) as an entrance into discussing random and systematic uncertainties. As a basis for that, a paper on this was written, see appendix D.10. The paper was intended only for Charles, but it turned out he had copied it on the back of the labguides, which he hand out at the introduction.

The entire class were to work with their labwork activities at the same time, since the school management has decided it being to expensive in teacher power to run labwork activities with only half of the class at a time[2], not allowing Charles to split the class in two parts.

It was not until this introduction it showed that he ran both the halftime and the halfwidth experiment at the same time, and therefore he explained the intended learning outcome of uncertainties as attached to both (or neither of the two) labwork activities. This is the first reason for why the data of Charles' two labwork activities will not prove valuable as a comparison experiment between two declaration levels. Later it showed that the students only handed in one of the lab reports. Thirdly, as it is seen from the introduction, Charles does not take ownership of the intention, and to some extent he is uncertain of the understanding of if.

First Charles tells about the halfwidth experiment, and asks the students what that means.

Charles The first [the halfwidth experiment] is about, is about lead and aluminium. You are to measure the half*width* and not the half*time* of lead and aluminium. Can you guess what halfwidth is?

A student explains how to place the plates between the source and the counter, and from that tells the halfwidth is when all radioactivity is stopped. Charles corrects it by telling it will never reach zero.

So the first point of the task is, when taking Charles's words literately to measure the half-width of aluminium and lead. He then states his second point concerning the need for report writing:

Charles But, what this is about, it is of course also, that we are to make a report.

As a third statement are the intended learning outcome which Charles was instructed to take:

Charles And in the labguide there is such a section called random and systematic errors. And that is what we are to focus on this time.[...]

Charles No I will try to see if I can handle this, because it is LBJ who came up with it.

As seen Charles does not take ownership of this purpose of the labwork when referring that it was all my idea, and he is not really sure of the point of it. The indication of Charles not understanding the point of placing such a purpose for a labwork becomes more evident when he introduces the terms of systematic and random error:

[2] This splitting of the class was the case for both Alice and Burt

Charles Well, but can you tell me, when I tell you something, please tell me which kind of error, well, if it is about random or systematic errors. Eh. Imagine standing at a junction and you are to count the number of cars passing through this junction pr. minute.

This is Charles's opening question for the discussion of systematic and random errors, inspired by the written introduction. From the question it is not obvious what is meant. The question could be interpreted as finding the number of passing cars of a specific junction at a given time, at a specific date. Or it could be interpreted, as was the intention, as the most likely number of passing cars for this specific place, but independently of the time and date.

The first girl interprets it as intended:

Girl Passing through?

Charles Yes, driving by, passing, or what it is called.

Same girl But that is totally different.

Charles You are just to stand and look at the junction. Normally when talking about a junction it is like this [shows his arms forming a cross] like 1, 2, 3, 4 roads, right? Normally there is always such a traffic light, right. So you have to stand and count how many passes such a junction pr. minute. What?

Same girl But that is very different.

Boy What if you run through a red light?

Charles Yes, ssh, yes, try to, what did you say?

Same girl I say, it is different how many cars that pass, it is like random in some funny way.

Several Rush hour, working hours.

Charles Yes, what is it dependent of, then. Do you measure at five am? Or is it at four?

Same girl You just take the average pr. hour.

The girl of this transcript excerpt does not yet have taken in the vocabulary of random and systematic uncertainties, and she talks about 'random in some funny way'.

She is then interrupted by a boy, which takes the question to be of the first interpretation:

Boy But there is still no source of error. There is no source of error if you just write what it is. If you write: 'I was out measuring one hour from eight to nine the 13th of December'. And then you are told that 30 cars passed, then where is the source of error? There is no source of error.

Charles I don't get it. One more time. I think...

Same boy You say there is a source of error, right?

Charles I haven't said there is a source of error, did I say there was a source of error? I am just saying I stand at a junction and I would like to count the number of cars passing. I haven't said there should be a source of error yet. It is you that are talking about it.

Girl You just say it is random.

Charles It is random, okay. But it depends on whether the traffic light is green or red, cause if you count the minute the red light is on, then how many is passing?

Girl It depends if any is passing from the other side.

Charles Then of course also cars pass by from the other side. What do you do, if you are to find out? Well, if the task it to answer how many cars passes through this junction. What will you do?

Girl In average?

Same boy It just says that in the exercise, how many cars pass by?

Charles But it can be that I send you out to determine it, what would you return with? Do you just go out and measure how many cars that pass, and then back and say 'here you go, 10 cars'?

Same boy I return and tell the number of cars that passed through a green light and the number of cars that passed through a red light at a given instance.

Charles Hopefully no one passed through a red light. Ssh, yes?

Same girl I would say, well, maybe 20 cars passed through in one hour or so. If I had longer time then say how many passed through in average pr. hour. Then you had more information then the number in total and for which period of time, then also the average.

Even though the boy have not taken in the words of uncertainties, he is familiar with the term *source of errors*, and he uses this to talk about uncertainties. His point is there is no need of talking about any kind of uncertainties, either random of systematic, if the task was to count the number of passing cars for a specific time and data, at least if you are able to count without errors. Instead of understanding the boy's point, Charles goes into defence about the task, maybe because of his own insecurity about the task, which he has not taken much ownership of. Instead of clarifying the task to the boy, he rephrases it in such a way, the task can still be interpreted in both ways. A girl takes over helping Charles by saying 'in average', which the boy does not accept, since it was not said by Charles himself. From then on the boy gives up on his point since no one understands him.

The discussion then continues of the process of making the observations and interpretations.

Charles Okay, yes?

Boy And then go out and measure during rush hour and then on time e.g. in the middle of the day, and then take the average of these two.

Boy Just put up a video camera. That is probably what I would have done.

Charles Yes?

Dennis I would do the same thing, take in more data at different hours and then do the average.

Several [mumbles] The more observations, one does... I would stand there for 77 hours.

Charles That is right. Take more measurements and find the right number.

Charles now gives up on the traffic task without ever getting to the point of the random and systematic errors and returns to safer ground of talking about the labwork activity.

Charles So to say - when we do an experiment like this - ssh - what would you say are the sources, what is it called?, the sources or error present? And would there be any sources of errors that repeat themselves, well, what is called systematic sources of errors? [Charles looks in the labguide]

Now Charles starts talking about systematic sources of errors, including a new term onto the already possible confusion between errors, uncertainties, systematic and random.

Boy If e.g. you hold some distance to the material and then..., then you would get different results. You should...

Charles Yes, that is right, and pay attention, that is why we have these holders today [...]

Charles You lock it to a certain position, so the distance between the Geiger counter and the source is completely fixed, nothing moves. And what happens if you move it between the measurements?

Boy Then it of course gets smaller, because it gets out in such a large angle.

Charles Yes that is correct. Yes, we use such a tube...

This male student is to some extent understanding how the intensity decreases with distance even if nothing in the air is stopping the radiation. This might not be intuitive, since the source itself is almost shaped like a gun firing in a specific direction. Charles though does not get a chance to pick up on this statement, since he is interrupted by another student:

Girl And then there is also the background radiation.

Boy Also the distance of reach for the various radiation types.

Charles If we do not subtract the background radiation, is it then an error, or is it... Would we even be able to see it on our graph in the end, if we subtracted it or not?

Boy No, we wouldn't if we assume it is constant and the same size for each measurement.

Charles It is just a number, it is just a number, it is just a number, which you should subtract. So in reality you would just see how it is only the law of radioactive decay. That is about the number of counts decreasing as a function of time. But you cannot see if you took the background radiation into account or not. That is what you call a systematic error, in other words the error is there all over and in reality you might not be able to see it in the graph.

The boy tries once more to have a discussion concerning the distance, but now Charles continues with the background radiation. I expect him to explain to the students how the background radiation is a systematic error, since for each measurement a small portion of the counts would be due to the background. But he gets around it rather clumsy by talking about how it can not be seen on the graph of the decays versus time or width of aluminium/lead plates, which is wrong. The background would be the number of counts still present after having waited a very long time or having placed a very large number of plates between the source and the GM-tube.

They continue:

Girl It just repeats itself.
Charles Yes.
Boy The background radiation is not of the same time every time, it is not constant, it is not like ten particles come at a time, or something.
Charles That is correct. Or ten counts.
Several Yes. You take the average. What do you do? Yes, yes, I know, but some places there must be. . .
Boy What if it is higher then what we say it is, due to the place we are. We would have a higher precision if we measure it first then by just saying it is here.
Charles That is right, but you *should* also measure it first, before you get started. Yes?
Girl The background radiation, you do several experiments and take the average to make it much more precise.
Charles Yes. So the background radiation is what we call a systematic error.
Camilla So we save it for a while, or what?
Charles Or what? What kind of random errors do you think? Which kind of random errors could occur during the labwork?
Girl It is something like forgetting to keep the distance constant.
Charles Yes. Or maybe an error in the [shows of the GM-tube]. Or, if there is an error in this, when it might be systematic, because it would actually repeat itself. Then you might need a table value to maybe investigate if the thing you measure is real or not.

Here Charles display a rather peculiar view of rights and wrongs in physics. It could be understood as if he perceive that everything can be tested against some book of all the truth of the world and anything the students can do is then just a reach towards the truth value.

Boy What if like you take time on your measurements? (. . .)
Charles Yes, and if the error repeats itself, then you wouldn't really realize it,

would you? On less . . . Or what do you think?
Girl Depends if you double-check it.
Charles With a table value. Or with others.
Girl Or repeat the experiment.
Charles Or repeat the experiment. Yes. Good.

Charles finishes up with dividing students into groups and spread them around the working area.

From Charles' introduction it is obvious he does not understand the point of declaring the intentions with the labwork, such as he was instructed to do. Both he does not see the point of it, and second, he is not really clear on his understanding of random and systematic uncertainties.

From this introduction it became clear how these data would not either support or reject the claim about a more likely reach of the intended learning outcomes of a labwork task if these are articulated and taken in by the students.

Left is Charles's purposes of the labwork activities, namely writing up a report (which to his understanding is very important in relation to the upcoming exam) and becoming familiar with the measuring of halfwidth.

Due to this disappointment it was chosen not to spend additional time on interviewing the students after the labwork activity. Later it showed how the group of students, who were followed chose not to hand in the second report of the half-time, so no full data access related to their learning outcomes of the task was provided.

4.5.4 Derek's introduction

Derek does two labwork activities, half-time and half-width. For the first labwork he was asked to explain as little as possible about his intentions with the labwork without being true to his normal working routine, and for the second we have been discussing the intentions of going into detail with random and systematic errors.

Half-time

This introduction is given to the entire class just before the labwork is to start. All of the students are doing the same labwork, and have met in the class for the introduction, and is thereafter spreading out in the surrounding working areas.

Derek knows the students are familiar with some of the pieces of the equipment, namely the GM-tube and the counter from a labwork in first year. The entire introduction lasts only 4 minutes.

Derek Well, hear me out; there are some technicalities in this labwork.
Girl There is some what?
Derek There are something you need to know, well, what this is about, is to

4 get some radioactive solution into a glass like this. Remember to measure
5 the background radiation; you know how to do that. Radioactive solution
6 into such a glass, it happens by pouring some of this liquid into it.

He continues explaining how to pour the eluding liquid into the isotope generator to gain a Barium solution, and emphasizes the importance of starting the measurements quickly after having obtained the radioactive solution. Having now explained this process, Derek turns towards explaining the counter. He guides the students to the cabinets with posts and holders, and concludes:

44 **Derek** Is it confusing to you?
45 **Several** No, no.
46 **Derek** Good. [. . .]
53 And if you have any questions then come to me. [. . .]
61 **Boy** Well, what are we waiting for?
62 **Derek** Absolutely right.

So for this labwork - quite as was intended, his introduction is sole to guide the students to operating the apparatus and gaining the needed data.

Halfwidth

Derek introduces the labwork of the halfwidth in two occasions. First, he spend half a module (approximately 45 minutes) on working with random and systematic errors, and a couple of days later, in the minutes before the labwork takes place, he gives a very short introduction to the labwork.

Random and systematic uncertainties module
Derek has as homework asked the students to read the introduction to random and systematic uncertainties, which also Charles used (see page 391). Taking off from that, Derek engages his students in a class discussion about the concepts of random and systematic uncertainties. As many of his modules, he asks the students to explain the concepts, and serves the role of writing on the white board and being the chairman of the class discussion.

He introduces this part of the module:

8 **Derek** Look, it is about uncertainties. Because in the next report you are to
9 write, you should focus on these different uncertainties. And let us then
10 talk about these uncertainties. What I would like to do today is that
11 we have a short discussion about this paper [the introduction paper they
12 have read before the class] and about the two uncertainties marked out.
13 After that you can do group works about uncertainties. And what you
14 are to do in these groups is to talk about your previous labwork activities,
15 and how the two types of uncertainties can be discussed in relation to the
16 labwork activities. To talk about how one can meet these uncertainties in
17 the earlier reports.

Then the first part of this module starts, and Derek asks his students what they can say about uncertainties. First the students name the two types of uncertainties, and Derek writes the two headlines on the white board. Then they start discussing random uncertainties, and the students discuss it in relation to an earlier labwork, where the students dropped a cake tin of paper to measure its time of fall from a large fall height. In relation to random errors, the students discuss puffs of air and its affect on the data.

Dana Random, that is like the time we did the cake tin experiment. With the fall times. It is, like, if a window is open then there could suddenly come a puff of air and affect the cake tins.
Derek Yes, that is right. So random things happen.
Boy Something you did not expect.
Derek Yes
Dana Because if were systematic, then we would know that a headwind would be there all the time, or a wind, and affect the cake tin.
Derek Yes. So it is embedded in the random uncertainties that some things from nature plays in and result in different data measurements. Yes? That made a lot of others wanting to say something about random… [Boy's name]?
Boy Can't you say that random uncertainties are something that affects some, but not necessary all? Opposed to systematic, e.g. an error in the weight or something like that affects all?
Derek Yes. You can say that. Affects all data.

Derek writes that random uncertainties affect *some* data and are difficult to control. This leads on to a discussion of how they can be controlled by e.g. closing all windows.

Derek prepares the ground for discussing repeating of measurements:

Derek What is the other way, so to say, that we can try to handle these random things which are to influence the experiment? What else can we do? And that we have done before? Yes?
Boy1 You could say, in relation to the result you could say plus minus the different…
Derek Yes, you could…
Boy2 Or you could include it.
Boy1 Well, what I mean is, you could say that I don't know it 100 [percent].
Derek How can you know it is an uncertainty of plus minus to, for example?
Boy1 Well, if you measure the wind resistance that occurs to plus minus two kilometres pr. hour. Yes.
Derek Yes, that is right. There is some statistics in this.
Boy3 Average.
Derek Yes, some average. What does it take to make an average?

Boy3 More experiments.

Derek Yes, that is right. You have to measure several times. That is right. That is the thing about reproducing the experiment. It is such a nice thing. Because, when you measure several times: It is boring to make statistics on only on instance. Well, one out of one child listen to children's radio, you can't say that. But, yes, more times. Statistics, and then we are happy, because then we can put thing on... Yes, it is a way to approach the case. That thing about it is difficult to control these uncertainties, when a puff of air comes by, to make statistics. But as you said, it is like tangible, well it is like, that was annoying. But it can also simply be uncertainties, which just are there, that we can't eliminate. E.g. the thing about it affects some data, maybe if we do three experiments, and for one of them there is a big puff of air, then of course it has affected some data, but not all. And some times, it is completely random, this uncertainty is random and we can't eliminate it. It is something related to how precise we can measure, e.g. How accurate can we measure, there has to be some margin of uncertainty? That is the plus/minus. How good is the apparatus? How small is the measuring interval? Or how precise is our ruler? It can also be the case that nature is random, like for radioactivity, were it is random, we don't know precisely how many will pass by. When we measure the background radiation, e.g. then we measure several times because... And we can't eliminate it, it is just a randomness of nature, we just don't know how many there will pass by.

They continue discussing repeating measurements or comparing measurements with others. They also discuss other uncertainties of the cake tin experiment, like the small differences of the cake tins.

Then they continue on to talk about systematic uncertainties. One student discusses if a weight measure 2 grams too little every time, and how that will be a systematic uncertainty. Another student discuss the case of a very warm day, which might cause thermic upthrust. Then one boy starts discussing radioactivity:

Boy No I again think about radioactivity; it is of course random at what time a nuclei decays.

Derek Yes.

Boy But it is again something, which affects all data. Well, isn't it like systematic, somehow? Because...

Derek Yes, yes, but...

Boy What is expected is that everybody gets something below the table value. Because there is so many uncertainties in relation to this. So it is expected to be uncertainties on all, all measurements.

Derek Yes, yes. That is precisely what I want to say. The thing embedded in these random and systematic uncertainties that is also what to do about them. Because when talking about random uncertainties, then it is all about measuring many times and do statistics. We have to have a lot of decays, e.g. Right? And then do statistics. You can't really do anything else then statistics. But for the case of systematic errors, then it is something about changing the setup to avoid these systematic errors. You cant really do it with background or radiation. Maybe in relation to background radiation, if that is what we are talking about. Then we could have done our measurements inside a lead box, then we could have shut out the background radiation.

This confuses the students, but now one student comes up with a clear cut example of a systematic error. He talks about an air track experiment, where it being lopsided would cause a systematic velocity increase or decrease. One could either fix it by putting the air track horizontal, or one could measure the lopsidedness and then correct for it in the data treatment. This cause the students to think all systematic errors can be corrected after the measurements have been taken in, and Derek comes up with the case of boiling water and measuring the energy consumption for this. Here the energy lost to the surroundings (electric cords, heating of kettle, heating of air etc.) cannot all be calculated, but they exist as a systematic error, causing the energy consumption for heating water to be measured too high.

From this introduction, it becomes obvious how Derek has taken in this intention of random and systematic uncertainties and made it his own. Also from the discussion, it is seen how the students are playing in and finding it interesting, though difficult to grasp in relation to their previous labwork activities.

From this basis, the issues experienced with Charles are not present for this case.

Short introduction to the halfwidth labwork
The halfwidth labwork is introduced with a short introduction and group formation. In the introduction the uncertainty aim is given again:

Derek You are to make an experiment about this thing with the halfwidth. Lead's halfwidth in relation to gamma radiation, which is right now laying over there and emitting like crazy. As homework you have read this page, the labguide. And remember, focus in this report - which is due to a date, which I have forgotten - focus is on - and you should include this in the report - this distinction between random uncertainties and systematic uncertainties, and how we can connect it to this particular labwork.

4.5.5 Comparison of teachers' introductions

For the case of Alice and Burt (the naturalistic cases), they are each true to their interviews and labguides in the way they introduce their labwork activities. Alice explains her three intentions, and spends only a short time on the introduction of apparatus and data handling. This on the other hand Burt spends a lot of time on making it reasonable to expect his intentions purely to engage in operating the apparatus, training them into plugging numbers into pre-given equations and writing up a formally looking report.

For the two set of experimental cases, Charles proved to be a difficult choice. He apparently did not take in the intentions related to uncertainties and ended out by almost casing them away and returning to the aim of getting data, handling data and writing the report. Also various technicalities went unexpected, such as him having the students do both labwork activities at the same time, such that the introduction of uncertainties could be related to both (or either) of the two labwork activities.

For the case of Derek, the introduction went much closer to the intentions. Derek accepted the intention for the labwork and presented it as his own. Also, the two labwork activities were separated in time in such a way that they could be compared in relation to the different degree of declaration.

4.6 Premises and preliminary conclusions

There exists some premises to the two research questions, which can (and should) be justified based on the data presented so far. These are

- Gymnasium physics students are exposed to somewhat the same labwork activities (there *do* exist such a thing as a typical series of labwork activities);
- Gymnasium physics teachers are not fully aware of the potential learning outcomes of their labwork activities, and it is possible for teachers to run labwork activities without being fully aware of the potential learning outcomes;
- Gymnasium physics teachers are not always declaring their intended learning outcomes of specific labwork activities to the students;

The data shown so far is able to justify and give further explanations of these premises.

Finally, the data should also prove the declaration level of the teachers' intended learning outcomes.

4.6.1 Students are exposed to somewhat the same labwork activities

Based on the described observations (pilots and in-depth), two claims can be made and justified relating to the type of labwork activities seen:

Firstly, closed-ended, guided labwork activities seem to be the mostly used teaching method for practical work. All of the in-depth cases are guided labwork activities, and for the pilots, most of them also run as cookbook exercises. And the in-depth case teachers (for the most cases) talk about them as being the most effective, and as often claimed otherwise, the students are according to the in-depth teachers engaging actively and positive towards cookbook exercises.

Secondly, the specific labwork activities done are somewhat similar across teachers, schools and districts. The in-depth labwork activities are to no extent unfamiliar and bare close resemblance or are identical to the labwork activities, which for example I was exposed to in the Gymnasium.

None of these hypotheses are unexpected or unknown, but still the claims need to be justified. E.g. Dolin (2003) poses the same claims, talking about classical experiments, cookbook exercises, and how labwork activities generally aims for teaching core content and evoke positive perceptions of labwork activities among the students:

> **Experimental work** is one of the most important characteristic features of the disciplines of the natural sciences, and it is ascribed a great significance among the teachers. The laboratory work is dominated by classical experiments done as cookbook exercises that are closed experiments based on a detailed labguide expecting only one outcome. This might be due to the fact that many teachers use experiments as presentations of core content (and not as a way of training the experimental method) and at the same time open labwork activities are seen as too time demanding and difficult for the students. It however needs to be underlined that the experimental area is a field where lots of creativity and urge of development is found, and where these experiences with benefit could be shared among the teachers.
> Even though the students perceive the labwork activities as a positive variation, a lot of the potential of learning which is embedded in the experimental work is without any doubt lost. The students experience the labwork activities as practical oasis as opposed to theory in the classes, which may cause a tendency to "hands on - mind off". The labwork activities may to a much higher extent then today be integrated in the daily teaching by using more time on students' preparation and processing in the classes; stop separating independent laboratory hours; use other and more open forms of labwork (e.g. more degrees of freedom, take-home labs, micro-scale experiments, virtual laboratories), etc.
> (Dolin (2003), p. 256, own translation, original emphasis)

Also international research points towards the many similarities of labwork activities across Europe. One of the conclusions of the study 'Labwork in Science Education' (LSE) was that the type and form of labwork activities used across a variety of European countries shared more similarities than differences (Tiberghien et al. 2001).

The argument of the similarities of labwork activities across Denmark will be further justified in chapter 6.

4.6.2 Re-design as obstacle dislodgement

An underlying premiss to the research questions is that Gymnasium physics teachers are not fully aware of the potential learning outcomes of their labwork activities, and it is possible for teachers to run labwork activities without being fully aware their potentials. Here is this premiss investigated and linked to the teachers' choice of running guided labwork activities. These results have previously been presented (Jacobsen 2009ab).

Based on the data concerning the teachers of the in-depth investigations, a possible answer can be given of why physics teachers in the Gymnasium continuously run guided labwork activities when research studies long have showed poor learning outcomes conceptually, procedurally and epistemologically. According to the review article by Hofstein and Lunetta (1982), the only thing guided labwork activities teach students better than other teaching activities is the subset of procedural skills that are specific for labwork activities, such as handling apparatus and other manipulative skills - and these specific skills have a questionable transfer value and a questionable learning value.

So why is guided labwork activities so often used? A number of obvious reasons can be listed:

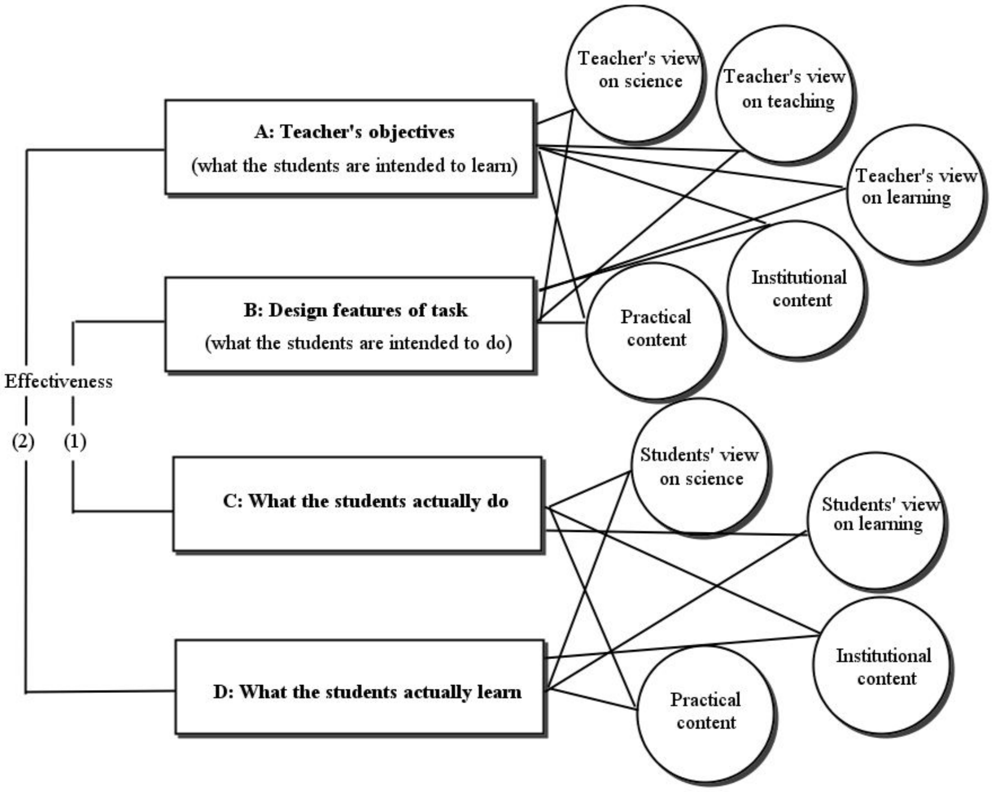
1. Teacher teach like they were taught themselves;
2. Teachers follow up on the methods as presented in books, journals, and internet sites;
3. Teachers teach as they were taught to by their mentors;
4. Teachers teach as they are told to by the curriculum;
5. Teachers teach in their comfort zone, and are afraid of the unknown;

These listed arguments are all acknowledgeable explanations, but not the ones to be pursued here. Instead the teachers' process of design, evaluation and redesign are investigated to answer the question.

To frame the investigating of the teachers' process of design, evaluation and redesign, great use has been found in 'the model of process of design and evaluation of a teaching/learning task', as this is developed throughout the European project 'Labwork in Science Education' (LSE), and as presented in e.g. Millar et al. (1998 1999); Tiberghien et al. (2001); Millar et al. (2002). The model describes the effectiveness of teaching/learning tasks, and explains the design and evaluation in a four-step procedure. This procedure is schematically displayed in figure 4.2.

For the first step of the design and evaluation process, the teacher decides on a learning objective, asking what the students are intended to learn from this task (A). This choice is affected by the teacher's view of the subject and of learning; also the practical and institutional context is in play. The teacher then design features of the task and details of the context, asking what the students

Figure 4.2 The model of process of design and evaluation of a teaching/learning task, from Millar et al. (1999).



actually have to do and what students have available to them (B). This design step B is affected by the same parameters as step A.

The following two steps concern the handing over of the task to the students, where the teacher (or in the LSE case the researchers) observes what the students actually do with the task (C) and what the students actually learn from the task (D). C and D are influenced by the students' view of the subject and of learning, along with the practical and institutional context in which the task is presented.

The effectiveness is in this model twofold. The first order effectiveness deals with B vs. C; to which degree the students actually do what was intended. This - according to Psillos and Niedderer (2002) - is an often neglected part of research on task effectiveness. The second order effectiveness deals with A vs. D, answering to which degree the students actually learn what was intended. Psillos and Niedderer state that this is the most common way of analysing the effectiveness of a task, but also by far the most complex thing to measure, leading to the always complicated control-group experiments, often lacking control of variables or deficiency of participants.

Alice, Burt, Charles and Derek talk about their design process as starting from step B, and as Alice states, only much later - when she had done the labwork a number of times - she became aware of intended learning outcomes of her labwork (see page 75). Only in the case of Alice, her intended learning outcomes were directly present in her design of the labwork activities. This idea about teachers start with step B is contradictory to the view the developers of the used model hold: "The starting point is the teacher's [...] objectives of the task. These specify what the students are intended to learn from the task. Having decided the learning objectives, the teacher then designs the labwork." (Tiberghien et al. (2001), p. 11))

All four teachers talked about the labwork tasks as redesigned from designs of colleagues, textbooks, internet sites and physics teacher's journals, chosen due to the need of usable labwork activities to cover all disciplines, as demanded in the curriculum.

If teachers start the design process at step B, it becomes impossible for the teachers to evaluate the second level of the effectiveness, since one cannot evaluate how well a task went according to a non-established parameter. Therefore the teachers evaluate their labwork activities based on how well the students accepted the task, and to which extent they did what the teachers expected them to do, and especially which difficulties the students met while doing the labwork.

Guided labwork activities show to be very effective on the first level; the students are extremely good at doing what the teacher wants them to do, even though the detail-richness of the lab-guides is not severe. It was found how extremely well-designed the guided tasks are, since almost all of the obstacles (conceptual, procedural and epistemological) were removed, replaced with a pre-rehearsed algorithm for writing up a report. This algorithm saved the students from hurdles of connecting theory to practice, how to manage data sets, how to draw conclusions, etc. This algorithm is established from manuals like the one found at Christensen and Limkilde (2007).

Students are doing practical works that are so 'well-designed' that the students are able to solve the tasks and hand-in reasonable good reports without actually needing to reflect upon the physical components involved in the task, see e.g. the statement by Burt at page 82.

Contradictory to what is often stated in research, the case teachers talk about that their students are positive towards the guided labwork activities. It is perceived to be a good way of making students hand-in well-written reports, which for the teachers indicate a high level of effectiveness. The students feel they were engaging in a meaningful activity, since they experience the learning of the algorithm as being a relevant physics task. The activities were viewed a having a reasonable degree of difficulty (easily solvable, but not banal).

When redesigning the labwork task, the teachers indirectly explained how their task is to dislodge the students' obstacles; making the labwork activities converging towards a smooth and highly effective task (of first level effectiveness). But it might actually be in the tumbling over the obstacles the potential learning is outplayed. But when the potential learning outcomes are not clarified, then the obvious way to redesign a task is by removing the obstacles.

The findings here give a different explanation of the reasons for choosing guided laboratory work then previously found. Teachers do not design from scratch, but redesign previously developed labwork activities, leading to a loss of the learning purpose (if ever existing). The labwork redesigns are evaluated only on the first level of effectiveness; success is achieved when students do what they are intended to do. The redesign process can then be characterized by dislodgement of the hurdles the students experience when conducting labwork activities. So to answer the question of why teachers stick to the guided labwork: If it isn't broke, why fix it. But, I claim, if the labwork activities are designed not for reaching a learning outcome, but to make the students do as intended, labwork activities as learning activities *are* broken, just not on the parameters the teachers use for validation.

Similar results are reported by Kirschner (1992), describing how labwork activities have been redesigned to make sure students do no run into major issues and problems during their work: "Years of effort have produced foolproof 'experiments' where the right answer is certain to emerge for everyone in the class if the laboratory instructions are followed." (Kirschner (1992), p. 278) The problem of this, he states, is that it does not represent real science, but instead display science as "... a body of information which is (and can be) verified and certain." (Kirschner (1992), p. 278)

Kirschner talks about the problems of foolproof experiments in relation to an insufficient understanding of the nature of science invoked on the students. But what Kirschner lacks, is the problems related to the possible removing of the learning potential in the task (not only in relation to nature of science), which might be removed in a well-meaning effort of making 'the right answer' more obtainable for the students. Not all labwork activities are sole holding the potential of gaining understanding of the nature of science, a plethora of other learning objectives for labwork activities exist, but they should be nurtured to make sure the baby is not thrown out with the bath water.

4.6.3 Declaration level

As seen from the data of the labguides and the teachers' introductions, not all teachers have considered or found it necessary or possible to declare their intentions with the labwork activities to the students.

None of the pilot teachers placed particular emphasis of explaining their intentions with the labwork activities besides how the experiments should be done in a pure practical sense. Especially for the case of PE physics due to the quite open task it showed to be crucial for the students' perception of the labwork task, that they did not fully grasp the teacher's intentions with the activity.

Alice to a high degree declared her intentions (such as displayed in the interview) with the labwork activity, both in the labguide and in her introduction.

Burt obviously had quite different intentions with the labwork; for him labwork activities are another way of engaging students in physics. Labwork activities are a teaching variety, and an entrance to engaging students with relevant homework for the cause of calculating and handling data. This he though does not make explicit, since it most likely is the aim of all labwork activities, and therefore does not need to be stated once again.

Charles was an experimental case, but a number of things went unexpected. Most seriously, he did not buy in on the intended learning outcome, which was set for the labwork, and therefore the case of Charles is omitted from further analysis.

Derek, finally, was a better experimental case, since he took in the planned learning outcome for the labwork as his own, and spend some time explaining the students what he (or I) meant by it for the second labwork, whereas for the first labwork the labguide and the introduction totally lacked any explanation of his intentions (such as it was planned).

Therefore on an axis of the declaration level, Burt and the first labwork of Derek will be at one side, and Alice and the second labwork of Derek will be towards the other end.

Part III

Linking labwork activities and their potential learning outcomes

5 Purposes of labwork activities

So, should labwork be included as a teaching activity in physics classes at the Gymnasium level? One could argue that by now the question is no longer relevant, since labwork is a completely implemented part of teaching physics (Wellington 1998b).

So if this is the case, then why discuss the aims of labwork activities? When I discuss my thesis with others, they often get confused about why I have spend such an immense amount of time on thinking about the purposes of labwork activities; physics is (among other things) defined as an empirical science, and therefore physics teaching *should* include labwork activities. End of story.

This view I understand - but find un-constructive. If students, teachers and researchers do not reflect upon the implemented school activities, the potential learning outcomes embedded in these activities are likely not to be met.

Others have discussed the same issue, and try to justify the need of such a discussion of labwork activities and aims:

E.g.

> For that reason, asking the question 'why do we do practical work in science education?' seems almost irrelevant, beside the point, a mere academic exercise. As many science teachers would answer, we do practical work 'because science is a practical subject'. There are, however, good reasons for asking the question. Perhaps the principal one is that much of what is said about practical work and the reasons for it simply do not hold up to close examination. The rhetoric of science education contains a number of popular myths about practical work, and its educational purpose, and these can significantly distort practice. By becoming clearer about the *real* purposes of practical work, we may be better able to plan appropriate practical activities which are more effective and efficient uses of learning time.
>
> (Millar (1998), p. 16)

and

> The aim of this paper is not to bury practical work in school science but to (once again) reconsider it. [...] We advocate that students should be made aware of the different kinds of practical work they do and the purposes of this practical work. In short, teachers should explain to students what type of practical work they are doing and why.
>
> (Nott and Wellington (1996), p. 807)

and

> ...the pupils' perceived purpose of the task is different from that of the teacher. Often teachers do not state the purpose. Even when they do they do not make

> sure that the pupils understand it. The tendency for pupils to construct as a purpose for a scientific classroom task either 'following the set instructions' or 'getting the right answer', was found in many classrooms which followed individualized programmes.
>
> (Tamir (1991), p. 17)

and in much the same way

> The pupil's purpose is different from that of the teacher. Often teachers do not state the purpose. Even when they do, they do not make sure that the pupils understand it. The tendency for pupils to construe either 'following the set instructions' or 'getting the right answer' as a purpose for a scientific task is evident in many classrooms.
>
> (Hodson (1993), p. 102)

A lesson intended to assist concept development might be very different in the design than a lesson intending to give the students an understanding of some aspects of scientific method, and so on Hodson (1993, p. 97).

and

> ...I have tried to show, using examples, the significant difference between the things which are said about the role of practical work in science education and the purposes which are implicit in the things which are actually done. There is more need, I think, to change what we say than what we do - though a clearer understanding of what practical work can and cannot do might also lead to better designed and more effective targeted practical works.
>
> (Millar (1998), p. 30)

and

"But while few doubt that practical work has a place in the teaching of science, we believe that there is a very real need to rethink the most appropriate purposes for practical work and the forms which it should take." (Woolnough and Allsop (1985), Preface)

The aims of labwork activities ought also to be discussed, since labwork activities as a teaching activity have been a target for much critique due to the fact that it is expensive, time-consuming, teacher-consuming, and have not proved effective in line of learning outcomes (Bates 1978; Hodson 1990; Lazarowitz and Tamir 1994; Watson et al. 1995; White 1996), e.g. by posing: "What does the laboratory accomplish that could not be accomplished as well by less expensive and less time consuming alternatives?" (Bates (1978), p. 75)

Having now argued for investigating the purposes for labwork activities in school, this chapter contains a thorough literature review concerning the purpose[1] of practical work as an educational method.

This chapter is a literature review of the objectives for labwork activities found in research literature as analyzed based on curricula (section 5.1), as analyzed

[1] intentions, aims, goals, purposes, arguments, potential learning outcomes, etc.

based on teachers' expressions (section 5.2), and as argued by researchers themselves (section 5.3). This is followed by a sixfold categorization scheme developed from the different sources. Each of the six categories is investigated in the following section: the conceptual domain at section 5.3.7, the procedural skills domain at section 5.4, the enquiry domain at section 5.5, the nature of science domain at section 5.6, the scientific attitudes domain at section 5.7, and the affective domain at section 5.8. The findings are discussed and linked to the current curriculum in section 5.9.

The literature reviewed concerns mostly 'science' (opposed to 'physics'), since most research literature deals with either this unifying school discipline, or generalize to science based on investigations in either of the science disciplines. Concerns of this are discussed in section 5.9.

For the same reasons, literature concerning all levels of education from primary school through lower and upper secondary school to education at tertiary level are looked into, and again a discussion of the problems of this is found in section 5.9.

On the other hand, the review has been limited to Anglophone and Scandinavian articles and books, sole due to limited language skills. As discussed in chapter 2 different research paradigms are the basis for research literature from various geographic areas, and this will be discussed along the way.

The literature chosen for the following review is more or less dated after 1975. This choice was made to keep the literature review less overwhelming.

Going through an immense amount of literature discussing the objectives for labwork activities, it shows how the literature falls into different categories, each with their own rhetoric related to the labwork objectives.

5.1 Curricula and purposes of labwork activities

The first entrance to investigating the purposes of labwork activities comes from interpreting curricula. Historically curricula have emphasized different purposes of labwork tasks, and the curriculum of today is the current result of these different views and the success and failure of their implementation.

5.1.1 Historical walk-through of curricula intentions with labwork

A historical walk-through of the arguments for and purposes of laboratory work in school physics/science is given here, showing how the intended learning outcomes of labwork in the last 100-150 years have experienced immense swings between emphasizing content versus processes and skills, where each of these are understood in somewhat different ways over the years.

Practical work has throughout history changed its position and role in the educational system within science a number of times. This section sets out to give an overview of the use of practical work in physics and science education, both internationally and nationally, to show the swings between positive and negative views of labwork, focus on content versus process, inductive versus deductive approach, etc.

Heuristic, inductive approach - high status

In the middle of the 19th century laboratory work first found its way into school settings, initially at universities. Prior to this period, science as a school subject was viewed less important than subjects of the humanities. In the period after mid-1800 science as a school subject grew in importance. Firstly since the social and economic importance of science began to be recognized, and secondly due to the growing agreement with *the heuristic approach* where students are taught to find out thing for themselves; learning occurs more effectively through action than through passive assimilation. Practical work as a way of learning science matched very well with the heuristic approach. The work method was based on inductive ideas.

Practical physics opposed to other science disciplines had the problem of expensive equipment, which often was both taking up a lot of space, was interfering with other pieces of equipment, and was being delicate possibly causing costly repairs when used by inept students. Physics labwork activities also took a severe amount of time not easily spared from already packed timetables constructed to serve literate disciplines (Layton 1990, p. 44). Qualitative investigations were seen as merely ‘play’, since the nature of experimental physics was viewed as based on quantitative studies, which lead to demands for time-consuming quantitative work. Conclusion was that student laboratory courses should provide strict training in accuracy of observation, precision of measurement and combination of inductive and deductive reasoning. These purposes were added perseverance and manipulative skills. The reality of these ideas soon lead to cook-book exercises (Layton 1990, pp. 44-45).

The first physical laboratory curriculum for secondary school in the UK was published in 1886 aiming for skilful manipulation, exact observation, intelligent and orderly recording of observations, principles of indirect measurement, the application and intelligent use of Arithmetic, Geometry, and easy Algebra, the varying of experimental combination, and common sense. This curriculum ended out by being misinterpreted by most teachers, degenerating the intentions to mere mechanical manipulations and observations lacking students' understanding. The ‘common sense’ purpose was discussed in relation to the emergence of quantum mechanics and relativity theory, which to a large extent worked counter-intuitive and lacked common sense (Layton 1990, p. 46).

Around 1900 the heuristic movement was beginning to fall in the UK, since it has in practise been proven that the inductive approach and the reliance of common sense did not make the students discover the scientific laws and connections, which the heuristic ideas intended (Gott and Duggan 1995, p. 18).

In Denmark the same ideas and movements can be recognizes, just some years later. In the early years of the Gymnasium in Denmark - from 1871 to the regulation of 1903 - the classical language disciplines were highly regarded (as opposed to the natural sciences), since the language disciplines were perceived as the main entrance to build up general education, which was the main idea which the Danish Gymnasium was build upon.

In this period student labwork in physics was not practised (Beyer 1992). In the years just before the regulation of 1903 practical work was tested among pioneer teachers, and their trials were reported positively.

With the Danish Gymnasium's regulation of 1903 the position of the school physics became strengthened compared to the earlier emphasis on the disciplines of humanities, who were seen as the sole provider of the general education ideas. And with the strengthening of physics, student laboratory work was implemented at compulsory level. The implementation of practical work was a part of the movement of self-acting[2], based on the heuristic approach, which by now was beginning to fall in e.g. the UK. Earlier on teaching strategies were not regarded important, but with this regulation, student motivation and independence were taking a leading role. Here practical work was seen as one - and maybe the best - method for self-acting. When comparing teacher demonstrations to student laboratory experiments the only seen problem concerning students' laboratory work was the increasing wear of the equipment.

In the early part of the 20est century very few critical statements about practical work in physics education were found. This is remarkable, seen in the light of the great difficulties involved in introducing practical work, which most teachers were not educated at doing or teaching.

Practical work was seen to meet a number of goals, like: tidiness; practical skills; autonomy; skills of empirical findings; critical abilities; personal experiences with phenomena of the nature; understanding of physical concepts; enjoyment of the work. Everyday experiences were taking into the classroom and seen as an introduction to the practical work. This perspective, though, disappear some decades later with the introduction of quantum mechanics and special relativity in the curriculum.

Students were asked to rediscover physical laws by use of observation; students were asked to use *the inductive approach.* On paper this seems a beautiful idea, but in real life it must have met a great number of challenges. Theories and models are not easily extracted from observations, and this inductive approach demands students to overcome in only a couple of years the problems of

[2] In Danish: selvvirksomhed

physics which historically have taken thousands of years. Even though this must have been discussed among the practising teachers, the debate is not found in the physics teacher forums existing at that time. Most likely, the teachers have taught practical work in another way than the curriculum demanded.

Some ten years after the introduction of practical work in the Gymnasium, the problems involved in teaching labwork activities were finally finding its way out in the open. Still the tone in the debate was positive - the use of inductive practical works as a way to learn physics was not questioned, only the teaching methods were debated. Debaters primarily pointed out the large work load the teachers was trying to overcome, gaining the skills needed for teaching practical work to their students.

Emphasis on the content - cookbook exercises - low status

A new movement emphasizing content over method appeared after the fall of the heuristic approach in the UK around 1900, thus giving a lower status of the practical work. The inductive approach was abandoned, replaced with using labwork as experimental verification of theories. This lead to cookbook exercises designed to verify theory or illustrate concepts.

Due to the routine and repetitive nature of the labwork activities of this period, questions of the value of practical work as a method for learning science began to emerge. But by now the labwork was a fully implemented type of activity in science classes, and abandoning it was not seen possible. This period lasted until the 1960s.

Also in Denmark the same ideas about content emerged, though again some decades later. After forty years of effort, finally in the 1940s the inductive philosophy as a teaching method fell. Mogens Pihl, an influential debater, claimed even very simple laws were not found by the students through inductive experiments. As was also the case in UK, labwork turned towards a verification approach, where the practical work was used to illustrate and verify postulated statements. At the same time the status of labwork decreased. Teaching theories and models were seen as more important than working in the laboratory.

Inquiry learning - discovery learning - scientific method

But at the same time with the turning away form the inductive approach in Denmark, the concept of the *scientific method* appeared as an argument for labwork activities. Earlier in the heuristic era, the purpose of labwork was seen as conceptual understanding and self-acting, not necessarily based on scientific methods. The idea of scientific method as a purpose of labwork lead in 1935 to a new decree for the science classes of the Gymnasiums, stating the importance of teaching the method of science. These changes were still found in the regulation of 1958. This scientific method was understood as how to act ‘in the proper way' in the laboratory, including planning, measuring, validation of results, and reporting. It was discussed if the practical works of that time included too complicated setups to ever meet the goals.

In the UK in 1959 Kerr started his investigations of teachers' ideas of the purpose and nature of practical work (see section 5.2 at page 140), which lead to results showing that teachers give little or no concern to the 'finding out' element of practical work. As a result of this a new movement - the *enquiry learning* or *discovery learning* - appeared, emphasizing discovery and scientific methods. Many of these ideas were identical to the heuristic ideas from earlier on. The intention was that students should be encouraged to discover science for themselves. Focus was on scientific method and objectivity. The underlying assumptions were that the pupil had no preconceptions (inductivist stance), so all observations were perceived neutral. The philosophy was "... to awaken the spirit of investigations *and to* develop disciplined imaginative thinking." (Nuffield Foundation (1966), original emphasis, cited in Gott and Duggan (1995), p. 18)

This approach has been criticized for its distorted view of scientific enquiry, showing of scientists as detectives, observations as theory-free and with a poor understanding of the transfer from experimental data to laws and theories (pure inductive process) (Wellington 1998b).

This philosophy lead on to the Nuffield schemes, a teaching approach including material originated from King's College in London. The Nuffield schemes became very influential, and the material and results still are still quoted in literature today, also outside the UK. But when implemented in the schools problems emerged. The practical works of the Nuffield schemes were carefully controlled, and the equipment was designed to make sure nothing could go wrong. Thereby the purpose of labwork activities was really to illustrate or refine concepts rather than finding out, opposed to the original Nuffield philosophy, often highlighted by a translate of the Chinese saying 'I hear and I forget; I see and I remember; I do and I understand.'

A critique of both the scientific validity and the learning value of the Nuffield philosophy of discovery learning is given by Hodson (1996, pp. 116-119).

Process and skills

Having realized the Nuffield schemes wrongly lead to a concentration on facts and theoretical knowledge over scientific methods, enquiry and discovery, a new approach appeared around 1985, namely the 'process and skills' idea or the 'process approach'. Within this approach learning science was largely subordinated to learning about science (Hodson 1996, p. 115), understood as a focus on the processes which scientific knowledge is acquired. The philosophy was that what still remains in the minds of the students after the facts has been forgotten is the most valuable elements of scientific education along with acknowledgement of how the facts have arrived, and not the facts themselves. Science knowledge has grown to such a large field, that no student will learn everything, and instead focus should be on how to access, use and ultimately add to the information store is the important thing to learn in science classes. The philosophy was that students are 'natural scientists', which gives the possibilities of allowing the school science to be driven by the students own interests and working methods, developing content-free science. Hodson sneers at these ideas: "Concepts follow 'automatically' from engagement in the processes, and are of little importance." (Hodson (1996), p. 120)

The process and skills movement sprang out of a time, where a number of factors spoke against content over process, such as: increasing evidence of the failure of content-oriented curricula, increasing interest in the 'Science for All' idea (Rutherford and Ahlgren 1991), exploding information load, developing information technology, and viewing of science processes as generic and transferable (Hodson 1996, p. 121).

The way this movement came to be used in class was by setting up small practical works to train specific skills, starting from simple skills to more complex process skills and eventually practical investigations. It was seen as if scientific enquiry could be described in terms of series of discrete processes, and each process is generic (context-independent). Also scientific knowledge emerges straight out of working with scientific processes. The final argument was the easy assessment of these skills.

The process approach was based on the myth of that skills and processes of science could be divorced from the knowledge base of theories and laws of science. The skills and processes was identified as observing, inferring, predicting and so on. These things were to be disembedded from their context and content, to be taught and learned separately, expecting the skills and processes to be transferable to other contexts (Wellington 1998b).

The process approach was criticized due to problems of incorporating these processes into a coherent scheme, lack of continuity in the different processes, along with pupils' problems in putting the different processes together appropriately when required to. A book edited by Wellington already published in 1989a stating some of the concerns of the skills and process approach.

The skills and process approach lead to a possible view of science as being a rigorous, algorithmic procedure applicable for all scientific problems (Hodson 1996, p. 115).

Constructivist approaches

The skills and process approach was again replaced with another philosophy of learning science, namely constructivism, which emerged from the 1980s and forward (Hodson 1996, p. 115). The earlier inductive ideas of science, where concepts emerged from pure observations and without relations to theory had proven itself wrong a number of times, and constructivism gave an answer to why this was happening. When the learner hold a misconception (alternative framework, etc.) of the content in play, the learner during the labwork might look for something other than intended, which will not change the conception they hold prior to the activity. Alternative, students adjust or modify "...their observations to conform with the expectations their existing theories give rise to. In other words, they 'see' what they expect to see." (Hodson (1996), p. 127)

Extensive research of students' prior knowledge and alternative conceptions fast established the constructivist approaches of teaching and learning science.

Hodson talks about four main steps in the constructivist approach: (1) identifying students' ideas, (2) creating opportunities for students to explore and test their ideas, (3) providing stimuli for students to develop, modify and possibly change their ideas, and (4) support their attempts to rethink and reconstruct their ideas.

In the constructive way of thinking about learning science, laboratory work plays a dominant role, since practical work can provide entrances to both step 2 and 3 (Duit and Confrey 1996, pp. 86-87)

The constructive approach emerged in Denmark, e.g. with the publications edited by Nielsen and Paulsen, with several contributions about labwork (Andersson 1992; Goldbech et al. 1992). In the Danish regulations of 1988, the emphasis of the scientific method is removed, and instead emphasis is placed on the individual learner, and e.g. the gender issue is taken up.

Scientific investigations - holistic approach

The constructive approach was again critiqued, e.g. with the argument that

> Scientific knowledge is more than personal belief reinforced by personally gathered information. It is an attempt to explain and account for the real nature of the physical universe (science has *realist* goals), regardless of whether it 'makes sense' in the everyday meaning of that expression. Indeed, much scientific knowledge flies in the face of common sense: the physics of Galileo, Newton and Einstein compares unfavourably with Aristotelian views in common sense is to be the arbiter.
>
> (Hodson (1996), pp. 127-128, original emphasis)

Woolnough (1991a) introduces the holistic approach in the form of scientific investigations, to overcome the problems encountered in the constructivism approach. These holistic investigations are designed to give students practice - and consequently the opportunity to develop competence in - in working like a real problem-solving scientist. Investigations are open-ended problems, and can take many different forms: half an hour to half a term, but most often of a few weeks of work; individually or in groups; in class or at home; related to the scientific content (leading into or derived from it) or independent of the ongoing scientific content. Investigations led students be problem solvers with a varying degree of autonomy. Important for investigations are that the solution is not obvious, neither to the teacher. Investigations allow students to use and apply concepts and cognitive processes as well as practical skills.

Up towards the next regulation of the Danish Gymnasium in 2003 (implemented from 2005) recruitment problems for tertiary educations of science grew large in the public and political debate. Along with the poor science results for Denmark in international surveys like PISA, TIMSS, ROSE etc. had a significant impact on the planning of the 2003-reform. Students performed badly on the science-content problems, but also their interests in science were very low and only few could see themselves proceed with further education within science, thought acknowledging the importance of science for the developing of the society.

Physics and the 2003-regulation has been highly debated e.g. in relevant journals (e.g. Wissing (2004 2005); Højgaard Jensen (2005); Hansen (2005); Nielsen (2006ab); Dolin (2007); Jessen (2007); Wissing (2008ab) and Laursen (2009)). Most debate runs on how physics was promised a prominent role to make up for the decreasing number of applicants to science educations at tertiary level, and how the teachers perceive the outcome of the reform as having a decreased amount of physics, along with a chance of how physics should be understood. Now emphasis is to a higher extent placed on meta-issues such as philosophy and history of physics, moving away from quantitative formulations of physics.

In the following section, the 2003/2005 curriculum for physics is analyzed in order to reveal the aims of labwork activities, as stated by this curriculum.

5.1.2 Purposes for labwork found in the 2003/2005 curriculum

With this 2003/2005 regulation, the discipline of physics for the first time becomes compulsory for all students in the Gymnasium. Physics is followed at the entire first year of the Gymnasium, opposed to previous reforms where students following the mathematical branch had to have physics at the first two years and had the opportunity to choose it at the last, whereas students following the language branch followed a two year science course.

The argument for teaching physics to all students is to enhance the science profile - outlived by increasing the total quantity of physics. The first year physics course then needed to be adjusted, in order to meet interests and abilities of all Gymnasium students. This has lead to a much more qualitative description of physics without equations and formulas, placing emphasis on the meta-issues of physics, such as nature of science and history. At the higher optional levels the quantitative description of physics is to be taught.

With the regulation, increased cross-disciplinary work is included, demanding teachers to cooperate with people from very different disciplines, holding different views on both teaching and the nature of knowledge.

The introductory part of the curricula for all three levels describes the identity of the school discipline of physics in the Gymnasium (Læreplan 2006cba):

> The scientific discipline of physics concerns the human trial to develop general descriptions, interpretations and explanations of phenomena and processes in nature and technology. *Through a interplay between experiments and theories a theoretically based scientific insight is developed, which stimulate curiosity and creativity.* At the same time it gives the background to understand and discuss scientifically and technologically based arguments concerning questions of general human or social interest.
>
> (Læreplan (2006c), p. 1, own translation, own italic)

This statement is further elaborated in the teaching guides (Undervisningsvejledning 2006cba). A description of the close bonds between the scientific discipline and the school discipline of physics is given, but as stated it should be notices that the aim of the school discipline is different from the scientific discipline, wherefor neither working nor thinking methods can be transferred.

Continuing, the teaching guide explains that physics offers the opportunity to gain answers to a number of different questions through many different methods of investigating and problem solving. Especially the controlled, scientific experiment plays a crucial role for learning planning and performing practical works, gaining knowledge of hypothesis making, model making and knowledge of their strengthen, modification or rejection through - for one thing - practical tests.

Further stated is that the teaching of physics must contribute to the understanding of physical theories, models and laws, and mind constructions (idealizations and simplifications of the real world, but can contribute to a systematization and realization of greater areas of knowledge).

Finally, physics deals with both the close and the distant, giving possibilities to promote interest, creativity and engagement.

C level physics

For the case of the C level in physics (which is mandatory to all students), the guidelines for the discipline is given by the curriculum (Læreplan 2006c; Undervisningsvejledning 2006c).

Physics is the only science discipline which is mandatory in the Gymnasium, and serves therefore as a primary introduction to general education.

The purpose of physics, as explained in (Læreplan 2006c), is the same as all other disciplines in the Gymnasium, namely for vocational and general education reasons. The discipline should evoke this by enhancing independence, skills of reasoning, analysing, generalization and abstraction, along with innovative skills.

Students need to gain basic insight in the scientific ways of thinking and methods of work, including experimental thinking and working. Also: “The experimental work provides the students with confidence with the interplay between theory and experiment, and thereby understanding the experimental ground of science.” (Læreplan (2006c), p. 4, own translation) Students are also to experience concrete problems of natural science along with their treatment, including the experimental side of the discipline.

Included in the vocational goals is mentioned how the students should be able to do simple qualitative and quantitative physics experiments, including posing and falsifying simple hypotheses. More specifically, the students are to do and describe experiments, but are not to autonomously design experimental investigations. Simple experiments are here understod as basic, clear setups, only depending of a single independent variable.

Posing and falsifying hypotheses are connected to students’ development of experimental competenc and the possibility to work with the scientific method (set up simple, qualitative hypotheses and testing of them in a systematic way). This presuppose the knowledge of safety, moments of risk and the ability to conduct decent laboratory practise. Also knowledge of common equipment (including it-based systems for data collection and treatment) is underlined. Students are to learn the meaning of sources of error and estimate uncertainties on measurements and results, e.g. on the basis of significant digits.

Data are to be presented reasonable in preparation for disclose simple mathematical connections.

Teachers should plan labwork activities, where the aims are given. An aim could be to do simple labwork and present a report with emphasis on data treatment, discussion and conclusion.

Here follows a list of the possible aims and potentials labwork holds according to the teaching plans:

- Labwork as a means to create good techniques in note taking through log books about labwork activities.
- POE[3] creates opportunities to think about the outcome
- Tool to treat physics concepts and relations.
- Labwork activities can introduce new topics, giving a common ground for all students.
- Not only reproduction, but also independence and creativity, wonder creates motivation
- First hand experience to physical phenomena
- Teach individual students after their needs
- Gain experimental competence
- Gain skills in presentation (communicate observations, results, experiences with concepts and relations)

[3] Predict-Observe-Explain (Gunstone 1991b).

- Gain skills in data analysis
- Illustrate/verify a theory
- Include theory in the data treatment
- Basic of modelling (support the creating of qualitative models or produce quantitative results for further data treatment)
- Support putting into perspective
- Develop personal competencies (creativity and independence), cooperation, observation skills
- Standard equipment
- Handling data
- Presentation of data appropriately

The C level physics include a examination, where references to previously done practical works should be found, if possible, making sure the experimental dimension of the discipline is included in the examination.

B level physics

Opposed to the C level, the B level of physics is optional for all students of the Gymnasium.

Besides a general raise of the level, an important difference concerning practical work is found under the headline of academic goals, where students now should learn - from a given problem - to plan, describe and perform physical experiments with given equipment and present the results desirable. This is a level up from the C level, where the students were only asked to describe and perform simple qualitative and quantitative physical experiments, including outlining and falsifying hypotheses.

Also on the academic goals of analyzing data, an update is included. Students should now learn to analyze experimental data in preparation to discuss mathematical connections through physical quantities. On the C level the students should only learn to present experimental data desirable and analyze them in preparation to establish simple mathematical connections.

According to the descriptions of working methods in the curriculum of 2003/2005 for the B level physics course, practical work should be an integrated part of the teaching, and it should ensure familiarity with experimental methods and the use of experimental equipment, including computer-based equipment to collect and analyze data. The experiments should be chosen according to a progression in the demands of student independence from simple registrations of experimental data to working with more complex connections to independent experimental investigations. Included is a least one long sequence, where the students in smaller groups work on a self-imposed, experimental problem. The time spend on the practical work should include at least 20 percent of the time in class.

It is important that the sub-goals of a labwork does not mutually work against

> each other. E.g. an open problem (which in principle require an unknown result) does not harmonize with a wish on focusing on communication of core content. It is important that the introduction to the labwork does not only clarifies the official goals, but equally much the more broadly competence aspects.
>
> (Læreplan (2006b), p. 24, own translation)

The exam at B level comes in two parts, where the first include a practical work of 1½ hour duration in groups of up to three students. They work on a known experimental problem, and they are allowed to use guides and handbooks. The exam is a conversation of the concrete practical work and the appurtenant theory. The assessment among other things is based on the studens skills on performing practical work and analyzing the collected data.

A level physics

A level physics is optional for all students having, but demands previous classes of both physics on B and C level.

Most important differences between the A and B level are the extension on the academic goals, where the students should learn to plan, describe and perform physical experiments to investigate an open-ended problem. This is again step up from B level, where the students should only be able to plan, describe and perform physical experiments from a given problem and given equipment.

The working method description has not changed from B to A level.

The examination has now both a written and an oral part. The written examination does not test anything directly concerning practical work. The oral examination still has a practical and theoretical part, where the practical part now takes 2 hours, and the labwork is no longer known to the students.

Again the assessment dealing with practical work is based on the student's ability to perform practical work and analyze the collected data.

Summery

This subsection contains a summery of the above found purposes for practical work and goals of physics, which reasonably can be addressed through practical work.

The academic goals concerning practical work found in the curriculum for the discipline of physics at level C, B and A can be divided into two: the planning and performing of the labwork task, and the analysing work of the received data. The grasp of the tasks increase with the school level and are represented in table 5.1.

When a framework for labwork purposes is developed the learning goals for labwork activities, such as these are given in the curriculum, are analyzed (see table 5.10 at page 186).

Table 5.1 Progression goals extracted from the 2003/2005 Danish Gymnasium physics curriculum.

Level	*Performing*	*Analyzing*
C	Describe and perform simple qualitative and quantitative physical experiments, including to make and falsify simple hypotheses	Present experimental data desirably and analyze the in preparation to establish simple mathematical connections
B	From a given problem plan, describe and perform physical experiments with given equipment and present the results desirable	Analyze experimental data in preparation to discuss mathematical connections through physical quantities
A	Plan, describe and perform physical experiments to investigate an open-ended problem	Analyze experimental data in preparation to discuss mathematical connections through physical quantities

5.1.3 Curricula aims

Researchers have over the last many years analyzed science curricula in order to understand the aims put forward for labwork activities. As discussed in the previous section at page 123ff, these purposes have changed in importance and understanding over the years. Still, some everlasting arguments exist, and are in various literature distilled to a few categories. The categories are here to be brought to light and then discussed.

Categorizing curricula aims

In here the arguments for labwork activities, such as researchers have found them in curricula, are categorized. These lists are often the take-off for critiques from various researchers. However, as will be shown in the following, the categories bare many similarities to the aims researchers put instead of these much-criticized categories from curricula readings.

Shulman and Tamir (1973) categorize the purposes and goals of school labwork activities, as they have found by analysing curricula and curricula analysis from the 1960s and early 1970s:

Skills e.g., manipulative, inquiry, investigative, organizational, communicative;

Concepts e.g., hypothesis, theoretical model, taxonomic category;

Cognitive abilities e.g., critical thinking, problem solving, application, analysis, synthesis, evaluation, decision making, creativity;

Understanding the nature of science e.g., the scientific enterprize, the scientists and how they work, the existence of multiplicity of scientific methods, the interrelationship between science and technology and among the various disciplines of science;

Attitudes e.g., curiosity, interest, risk-taking, objectivity, precision, confidence, perseverance, satisfaction, responsibility, consensus and collaboration, liking science;

Hofstein and Lunetta (1982) argue that these objectives are almost synonymous with those defined for the school subject of science in general. This does not necessarily prove the objectives wrong, but it naturally calls for a discussion of whether these objectives can be met by other and less time-consuming, less expensive and less teacher-demanding school activities.

All of these five objectives are recognized in the case teacher interviews.

For the case of *skills*, Derek talks about learning general skills related to labwork activities and engagement in data treatment and the mathematical side of it. Alice talks about how labwork activities can invoke intensive work with physics tasks through the report writing.

For the case of *concepts*, Alice talks about illustrating and understanding theory through iteration between theory and experimental data. Burt and Derek talks about learning theoretical physics. Derek separates the argument into two: as a justification of presented theories and as an argument for the relation between theory and nature.

In the case of *cognitive abilities*, Derek talks about learning hypotheses making.

For the case of *understanding the nature of science*, Burt talks about epistemological reasons, and Derek discusses how physics is (among other things) defined by labwork.

Finally, *attitudes* are represented in Alice, Burt and Derek, talking about liking to do physics and engaging in physics in alternative ways.

As discussed by Charles, there are other arguments for doing labwork activities not mentioned here. These arguments, which are of a less didactical kind are those of fulfilling the curricula needs, preparing the students for the exam, being able to motivate the class (not to do physics, but to do something), improving the teacher's status in class, having the opportunity to engage in one-to-one discussions with the students, giving a valid argument for homework, etc. etc.

Whereas Shulman and Tamir (1973) discusses the science generally and for various school levels, in somehow the same terms Newton (1979) discusses laboratory work in physics for the last two years of the British upper secondary school (students aged 16-18).

According to Newton (1979) practical work in schools was at that time expecting to fulfil a wide range of aims stated in the curriculums, which by no means were possible. Newton divides all stated aims for practical work within the four groups:

Didactic aims Clarify, order and extend experiences of natural phenomena, illustrating laws;

Skills Use of apparatus, specific manipulative skills, standard techniques, comprehension and execution of instructions, communication of results and conclusions;

Scientific method Creative and logical reasoning, disciplined approach, critical attitudes;

Affective aims Interest, enjoyment, attitudes of perseverance, open-mindedness, critical mindedness, objectivity, intellectual honesty;

For the *didactic aims*, he states, it is important that practical works are direct, so the shown result or phenomenon cannot only be understood by a complex explanation.

When wishing to apply a practical work with the aim of developing *skills*, Newton emphasises, one should always question whether the particular skill is important (was a wider relevance), or is so specific for the situation that the learning of it is irrelevant.

Newton (1979) explains how discussions have been running on the possible danger of overemphasizing the aim of *scientific method*, since the major aims should still be the illustration of theory along with skill development. Newton emphasizes there is no such thing as *a* scientific method, and this should be underlined when using labwork activities for teaching about scientific methods.

Newton (1979) states how criticality, perseverance, objectivity and intellectual honesty is needed to be a scientist, and students should be at least presented and initially acquiring these attitudes. On the other hand interest and enjoyment are not obligatorily present at a good scientist, but are still worthwhile to enhance.

In the Nordic research and development project NORDLAB concerning factors of mathematics, science and technology teaching, Denmark worked specific with laboratory work. In the final report, Goldbech and Paulsen (2004, p. 7) review how Nordic curricula in science places great emphasis on labwork, since it is expected to help students to:

- gain interest and motivation
- experience and observe phenomena in nature and the lab
- learn the scientific concepts by observing them in a context
- learn and use the scientific processes and methods (especially skills of reasoning and arguing about relations with their surrounding world)
- develop practical and observational skills

- develop social skills and attitudes due to group work
- understanding of the epistemology of science (relation between theory and experiment, insight to how scientific knowledge is created)

Højgaard Jensen (2002) describes the purposes of labwork activities, as these are often described, as falling in the same categories as Newton (1979):

> . . . labwork is a motivational way of approaching theoretical concepts; as a means to learn measuring techniques, data treatment, calculating with units or to gain understanding of uncertainties; or as something which can be used to develop respect for data and an understanding of the 'scientific method'.
>
> (Højgaard Jensen (2002) p. 38, own translation, original quotation marks)

As seen, the arguments distilled from the curricula from different times fall under the same set of categories: theoretical concepts, skills and techniques, scientific method, cognitive abilities, understanding nature of science, and affective and attitude reasons. To a large extent these aims still exist in the current Danish curriculum, as seen in section 5.1.2.

Critiquing curricula aims

According to Hofstein and Lunetta (1982) it is around that year educators begin questioning the effectiveness and the role of laboratory work; posing for the case of laboratory teaching that it is not as self-evident as prior believed (as also seen in section 5.1.1). This coincidence with a retreat from the student-centred science activities, which results in less time spend in the laboratories.

Hofstein and Lunetta (1982) critically review a number of empirical research studies of the 1960s and 1970s, investigating the difference in learning from practical works compared with other learning methods, and only a difference in the learning was found in the development of laboratory manipulative skills:

> Most of these research studies have shown no significant differences between the instructional methods as measured by standard paper-and-pencil tests in student achievement, attitude, critical thinking, and in knowledge of the processes of science. Not surprisingly, the one area in which the laboratory approach showed measurable advantage over other modes of instruction was in the development of laboratory manipulative skills.
>
> (Hofstein and Lunetta (1982), p. 202)

And the value of these laboratory manipulative skills have long been discussed. This, they state, should thought not lead to a doom of practical work in schools, since most of these kind of comparison studies have shown a hinder of learning, and the results might be due to problems in the collection and interpretation of data, such as the selection and control of variables, the group sizes and the instrumentation used during the empirical surveys, the teacher behaviour, and the laboratory manuals used.

Woolnough and Allsop (1985) are not questioning if labwork activities should be a part of the teaching of science, but question how and why labwork activities are used. In this critique they list the problems of the performance of practical work (Woolnough and Allsop 1985, pp. 3ff), such as no or small connection between how practical work is conducted among scientists and students. Students' practical work, they state, is closed, convergent and dull, as opposed to scientists' experiments being the opposite. At the same time they refer several studies showing how practical work does not serve the learning of theory. Finally, an enormous amount of money, time and effort is spent by teachers on practical work. This call for a rethinking of the labwork aims (see 5.3.3).

Another acknowledged and hard critic of labwork activities is Hodson. Hodson (1990) discusses how practical work contributes little to *learning of science*, *learning about science* or *doing science*:

> ... practical work, as conducted in many schools, is ill-conceived, confused and unproductive. It proves little of real educational value. For many children, what goes on in the laboratory contributes little to their learning *of* science or to their learning *about* science. Nor does it engage them in *doing* science, in any meaningful sense. We need to ask, as a matter of some urgency, how this state of affairs has come about and, more importantly, what we can do to remedy the situation.
>
> (Hodson (1990), p. 33)

One of the reasons for this poor state of laboratory work is that, he describes, how teachers use experimental work unthinkingly. Still there are some good things to labwork: "Some teachers teach some goals to some students successfully, but most practical work has a poor outcome." (Hodson (1993), p. 105). Finally, Hodson concludes as Hofstein and Lunetta (1982) that too few and too poor research studies has been done in this field of science labwork activities to prove or reject the arguments for labwork activities.

Also Tamir (1991) criticizes labwork and their aims, such as they are presented in curricula. Quoting Anderson (1976), he states that the role of students in a science laboratory does not resemble the role of the scientist, but most often the role of the technician. Tamir lists various reasons why students retain the intuitive views even after a practical work has been designed to teach the consensus science viewpoints.

- Lessons are perceived by pupils as isolated events, not as part of a related series of experiences as intended by the teacher;
- The pupils' perceived purpose of the task is different from that of the teacher;
- Pupils fail to understand the relationship between the purpose of the investigations and the design of the experiment, which they carry out;
- Pupils lack assumed prerequisite knowledge;

- Pupils perceptions relating to the significance of task outcomes achieved are not those assumed by the teacher;

Tamir (1991) comments on the different aspects of practical work for the variety of disciplines under the headline of science, where he described physics as

> In the physical sciences students make observations, measure and perform experiments. Yet, they often use instruments which translate the actual phenomena into data without being able to observed the actual phenomena directly. [...] In the physics laboratory students who work with electrical circuits are expected to explain their observations in terms of the behaviour of electrons which they are not able to see. The lack of direct perception is characteristic of much laboratory work in the physical sciences.
>
> (Tamir (1991), p. 19)

Having now presented the summarized categories of labwork aims such as they are found in curricula over a large period of time, and a general critique of them, we now turn towards the labwork aims, such as they are found among teachers.

5.2 Teachers and purposes of labwork activities

One of the first investigations of the purposes teachers hold for labwork activities in science is done by Kerr (1963). A number of teachers teaching students at age 16-18 are asked to rank 10 labwork aims. The investigation is repeated in 1975, 1996 and 2009 (Kerr 1963; Woolnough 1998; Abrahams and Saglam 2009), and their findings can be found in table 5.2.

As seen the interest aim (aim 9) scores low in the first study and increases throughout the years. For the case of the conceptual domain (aim 6 and 7), it scores fairly high the first years and decreases. Aim 10 of gaining experience with physical phenomena increases. The enquiry domain (aim 4) increases from a very low status in 1963, but seems to fall again in the last survey. Skills (aim 3) seem to score high at the first survey and degreases from then on.

Whereas the repeated Kerr-study concerned *science* teachers, in the papers by Boud (1973); Boud et al. (1980) a survey of the aims of labwork as found by staff teaching and students taking undergraduate *physics* laboratory programmes are done. The staff members and students were asked to rate 23 labwork aims by their degree of importance (1 is top rank)

As seen at the table for the staff, most emphasis is placed on attitudes, skills and enquiry, and less emphasis is placed on the conceptual domain and the domain of nature of science. The affective domain is also rated fairly low.

Quoting Ogborn (1977), Boud et al. states “One cannot achieve everything on would like to achieve, not only because time is too short, but also because

Table 5.2 Kerr-study and follow-ups investigating science teachers' aims of labwork activities. The 2009 numbers are not given, but statements of their tendencies compared to the 1963-numbers are indicated by arrows. 1 indicates teachers' rank the aim as most important, and 10 indicates least important.

	Labwork aims	*1963*	*1975*	*1996*	*2009*
1	To encourage accurate observation and careful recording	1	1	1	↓
2	To promote simple, common-sense, scientific methods of thought	4	3	2	↓
3	To develop manipulative skills	6	5	7	↓
4	To give training in problem-solving	8	7	3	→
5	To fit the requirements of practical examinations	10	9	9	→
6	To elucidate the theoretical work so as to aid comprehension	2	6	5	→
7	To verify facts and principles already taught	5	10	8	→
8	To be an integral part of the process of finding facts by investigation and arriving at principles.	3	8	10	→
9	To arouse and maintain interest in the subject.	9	4	6	↑
10	To make physical phenomena more real through actual experience	7	2	4	↑

aims compete with one another." (Boud et al. (1980))

Boud et al. state which aims were ranked highest and lowest by each of the three groups, and found to a large extent agreement, but naturally also including some differences.

No work is done on characterizing the 22 aims; they obviously find the agreements and discrepancies between staff and students more important than actually digging into the nature of their aims.

Concluding, they state about the use of their results in designing of courses including practical work

> In this context, it may be suggested that consideration should be given by course developers to the incorporation into their courses of means whereby students become aware of the principles on which the course relates to particular employment possibilities.
>
> (Boud et al. (1980), p. 427)

Table 5.3 Boud-study investigating physics teachers' and physics students' aims of labwork activities.

	Labwork aim	*Staff*	*Student*
1	to instil confidence in the subject	12	19
2	to teach basic practical skills	15	11
3	to familiarize students with important standard apparatus and measurement techniques	6	13
4	to illustrate material taught in the lectures	19	21
5	to teach the principles and attitudes of doing experimental work in the subject	3	5
6	to train students in observation	5	6
7	to train students in making deductions from measurements and interpretations of experimental data	2	2
8	to use experimental data to solve specific problems	7	18
9	to train students in writing reports on experiments	16	3
10	to train students in keeping a day-to-day laboratory diary	9	10
11	to train students in simple aspects of experimental design	8	9
12	to provide closer contacts between staff and students	14	23
13	to stimulate and maintain students' interest in the subject	13	17
14	to teach some 'theoretical' material not included in the lecture	20	15
15	to foster 'critical awareness' (for example extraction of all information from data, avoiding systematic errors)	1	4
16	to develop skill in problem solving in the multi-solution situation	18	20
17	to simulate the conditions in research and development laboratories	10	22
18	to provide a stimulant to independent thinking	11	8
19	to show the use of 'practicals' as a process of discovery	4	18
20	to demonstrate the use of an experimental method as an alternative to the analytical method and solving problems	22	16
21	to familiarize students with the need to communicate technical concepts and solutions	21	7
22	to provide motivation to acquire special knowledge	23	14
23	to help bridge the gab between theory and practice	17	1

In the European LSE study (Labwork in Science Education) a list of aims for labwork activities is developed (Welzel et al. 1998). This list emerges from answers from European upper secondary and university science teachers when asked for their aims of labwork activities.

The list along with the ranking from the science teachers participating in the survey are found in table 5.4.

As seen most emphasis is placed on ‘linking theory to practice’, which of course sounds appealing, but is not really revealing what is meant. Looking through the sub-aims, both conceptual ideas (such as improving understanding of theory and verification of scientific laws) as well as procedural ideas (make specific experimental methods explicit and improve systematic approach), as well as performing enquiries (solve problems which arise from an experiment), etc. are included under this headline.

Second most important is ‘getting to know the methods of scientific thinking’, which related to cognitive and enquiry ideas, which also when looking at the sub-skills reveal a bit of a melting pot.

Third is ‘to learn experimental methods’, which related to the skills idea, but when looking at the sub-aims revealing a fairly low taxonomic level.

Lowest is the affective ideas and the unimportant ‘evaluating the knowledge of the students’.

After this investigation further work has been done by e.g. Séré et al. (2001); Goldbech and Paulsen (2004); Högström and Ottander (2005).

5.3 Research literature and purposes of labwork activities

Another way to unveil aims of labwork activities besides investigating curricula and teachers’ opinions (though intertwined) is to investigate the purposes of labwork activities as discussed in the science education research literature.

I will in the following review a few significant authors discussing the aims of labwork activities in science. Their categories will then play the basis of developing a list of labwork aims.

The labwork aims - such as developed and discussed by science education researchers - are reviewed. A typical way of reporting research-based aims is starting out by critiquing curricula or teachers’ aims, and then setting up a new list of aims. These ‘new’ aims often bare more or less a close resemblance with the ‘old’ aims, but are now interpreted in a less simplistic way, instead emphasizing the complexity of science and the complexity of the teaching of science.

Table 5.4 Results of the LSE study concerning science teachers' aims for laboratory work. Each of the boldface aims were ranked between 1 and 5, where 5 indicate most important. The sub-aims are written hierarchically, such that the one ranked most important is listed first.

Category	*Rank*
Link theory to practice	4.1
Improve understanding of the theory	
Verify scientific laws	
Make phenomena occur	
Understanding of theory through practice	
Illustrate phenomena	
Make specific experimental methods explicit	
Experiments which will be used in discussions	
Improve systematic approach	
Introduce notation and technical terms	
Solve problems which arise from an experiment	
To demonstrate technical applications	
Help remember facts and principles	
Learn experimental methods	3.5
Get experience in standard techniques and procedures	
Learn a method using an example	
Learn and practice how to write a lab report	
Learn how to make careful observations	
Learn working in a proper and safe way	
To handle experimental errors	
Get to know the methods of scientific thinking	3.7
Get to know the scientific approach	
To learn how to think scientifically	
Develop scientific skills of planning and experimenting in general	
Develop a critical approach in interpreting data	
Learn and handle science as complex networks	
Get to know epistemological methods	
Get to know how scientists work	
Learn to deal with equipment difficulties	
Foster motivation, personal development, social competence	2.5
Develop interest	
Enjoy subject and activity	
Develop general skills of communication and interaction	
For the teacher to give and for the students to get motivation	
Learn how to work in teams	
Develop awareness of natural environment, responsibility, tolerance (ethics in science)	
Evaluating the knowledge of the students	1.3
For the teacher to evaluate the knowledge of the students	

This section serves to review the type of categorizations for labwork aims, and is not intended to unfold each of the categories. This is instead done in the following sections, where each of the found categories is presented.

There are several approaches to build up such a review of categories. E.g. one could build it chronologically. Or - and that is what I have chosen to do - one could to build it up from the least to the highest degree of details.

5.3.1 General education versus vocational reasons

To start the categorization of the aims of labwork activities, one could pose the division between vocational reasons versus ‘general education’-related reasons, such as the two-fold aims of the Danish Gymnasium for all disciplines are given. This discussion is recognized by Woolnough (1991c), who talks of vocational reasons (to provide students with such knowledge, skills and attitudes as they will find useful in later working life) versus cultural reasons (to enable students to appreciate both the discoveries and the ways of working in science). Also Hegarty-Hazel (1990c, p. 4) puts forward this division, when she emphasizes the importance of dividing the discussion of practical work in the categories of general education and induction into professional science, and as she states, these often do not go together. She states often tertiary level educators emphasize the latter reason, whereas secondary school teachers and researchers emphasize both arguments, not necessary being clear of the distinction.

This division are useful in the sense that labwork activities designed for reaching specific skills relevant for vocational reasons might be of a very different nature that those designed for cultural reasons, and as Hegarty-Hazel (1990c) and the Danish curriculum state, both arguments are valuable on the Gymnasium level.

On the other hand, the division is not very useful to give clear indications of the potentials embedded in specific labwork activities, and a further categorization seems to be needed.

5.3.2 Procedural versus conceptual

Another way of discussing the intended learning outcomes of labwork activities are the ‘knowledge that’ and the ‘knowledge how’ (also known as *substantive knowledge* and *syntactic knowledge*, or scientific knowledge and scientific methods) (Schwab 1974; Hegarty-Hazel 1990c; Nott and Wellington 1996). This discussion is somehow related to the discussion today about core knowledge and competencies.

Also Millar (1991 1998) describes how science education should both be concerned with telling and showing, understood by both teaching theory and practice: or the *conceptual understanding* - the learning and understanding of science concepts, and the *procedural understanding* - developing competence in the skills and procedures of scientific enquiry. Often it has been put forward that these two goals can be met simultaneously, which Woolnough and Allsop (1985) and Millar (1991) are sceptic about.

Millar et al. (2002) state how the fundamental purpose of any labwork task is to help students to make links between the domain of real objects and observable things, and the domain of ideas. As they say, through labwork activities, students also learn about the scientific approach to enquiry. This intended learning outcome of labwork tasks they then further interpret as falling into two categories: content and process. These two domains are then interpreted as a number of categories:

Content identify objects and phenomena and become familiar with them; learn a fact (or facts); learn a concept; learn a relationship; and learn a theory/model.

Process learn how to use a standard laboratory instrument of piece of apparatus; learn how to carry out a standard procedure; learn how to plan an investigation to address a specific question or problem; learn how to process data; learn how to use data to support a conclusion;and learn how to communicate the results of labwork.

In the twofold division between conceptual and procedural knowledge, some problems should be addressed. Firstly, as also the referred authors indicate, there is a gab between technical skills and processes of enquiry.

Secondly, for the discussion of *knowledge that* and *knowledge how*, left behind is the discussion of nature (or philosophy) of science.

Thirdly, also the non vocational arguments are left behind. The non vocational arguments are, as described by the case teachers, variety from other teaching forms, fulfilment of the curriculum demands, practise for upcoming exam, etc. etc. As part of this, also the affective arguments are missing, both those of interest and motivation, but also by invoking the attitude of self-dependence and self-confidence in addressing problems in and outside school science.

5.3.3 Procedural understanding, conceptual understanding and enquiry

Based on these identified lacks another categorization of labwork aims is looked into, placing emphasis on procedural understanding, conceptual understanding and enquiry (or cognitive processes).

Woolnough and Allsop (1985) are the first to call for such three-fold interpretations of the aims of labwork activities. These aims are all central to scientific activity, and according to the authors fully justify the use of practical work. They also state that these aims are specifically and distinctly related to an education in science, but they have a more universal utility, giving them an argument in general education for all rather than for vocational training for the few. Woolnough and Allsop (1985, p. 41) describe their tree-fold list as:

Developing practical scientific skills and techniques Observing (carefully, honestly and perceptively); measuring; estimating; manipulating; recognizing similarities and differences; appreciating what is significant; being able to measure a variety of properties; using scientific instrument (where human senses are lacking); estimating values for physical quantities; making sensible approximations; handle apparatus and equipment safely and appropriate; develop appropriate experimental techniques; planning, executing and interpreting the results; manipulating and making sense of data; appreciating the extent of its reliability.

Being a problem-solving scientist PRIME (**P**roblems to be tackled, **R**esearch into the appropriate factors, **I**deas about ways of attacking the problem, **M**aking the device or experiment, **E**valuating the outcome). Open-ended, divergent, no predetermined fact or theory.

Getting a 'feel for phenomena' Science is about getting acquainted with the physical world we live in, and making sense of it; building a reservoir of tacit knowledge.

They state the first aim of developing practical scientific skills and techniques is needed, but also has the dangers of becoming an end in itself.

As reading their arguments for the three-fold categories of labwork aims, it seems the skills-aim and the phenomena-aim are actually means for reaching the third aim of being a problem-solving scientist. This is later further developed and argued for by Woolnough (1991c) when discussing a 'step-up' approach versus a holistic approach:

> Do pupils learn by a 'step-up' approach whereby pupils are encouraged to master basic skills *first* and are *thereby* enabled to progress to more complex process skills and *eventually* practical investigations [. . .], or do they learn best by a holistic, experimental approach whereby they are encouraged to do small, but complete, investigations from the earliest stage, progressing to more difficult investigations later and picking up the appropriate skills when necessary? Do pupils develop their investigational ability best by learning the bits and putting them together or do they learn to do investigations by doing investigations? Such questions lead to the more pragmatic issue of the type of practical work we set our students. Do we set them 'standard exercises' to develop their skills? Do we give them 'routine experiments' to develop a feel for a particular phenomenon? Or do we expect them to do 'practical investigations' to build up their own competence at working as problem-solving scientists?
>
> (Woolnough (1991c), p. 5)

As hinted, Woolnough buys in on the holistic, experimental approach:

> Practical science provides the opportunity to develop them all, together, not in a reductionist way of trying to develop each in isolation of the others; certainly not by concentrating on the knowledge and skills elements only and trying to build up from them; not by insisting that each component is separated out to be assessed reliably to see how well it has progressed since it was last measured; but by giving students the opportunity to play, to practise and to explore in a safe

> but stimulating environment as they investigate scientific tasks in the laboratory and the local environment. If we can leave our students with a sense of self-confidence in their ability to tackle scientific problems and have stimulated them by the fun and challenges of science, we will have equipped them with vision and a pair of stout walking boots well prepared to deal with the next unexpected challenge.
>
> (Woolnough (1991b), pp. 187-188)

As he states: "First, the whole does not equal the sum of the parts. Second, the whole is greater than the sum of the parts. Third, the whole is altogether more powerful than the sum of the parts." (Woolnough (1991b), p. 185)

Still, he holds on to the skills argument and the phenomenon argument, as these will come into play while working on as a scientist:

> At the heart of scientific activity must be the practical *investigations*. Whether such investigation last for a few minutes or a few weeks, whether it concerns a scientific relationship or a technological problem, the process of planning, performing, interpreting and communicating, with its continual modification through feedback, is fundamental to the way in which scientists work. Other practical work may lead up to the most complete form. When it is necessary to develop a particular skill or to become familiar with a particular piece of apparatus a practical *exercise* may be needed, though even here it is appropriate to incorporate that exercise into a genuine scientific activity rather than attempting to develop that skill out of context. Finally, practical *experience* is designed quite specifically to give the student a feel for the phenomena under investigation, to build up personal experience and tacit knowledge which will form the basis for subsequent action and understanding as links are formed.
>
> (Woolnough (1991b), pp. 185-186, original emphasis)

Another way of describing the tree-fold aims are found at Gott and Mashiter (1991). As a way to get about the aim of learning the 'correct' concepts, Gott and Mashiter (1991) develop a 'process aim', placing more emphasis on its methods rather than focusing exclusively on its products. The processes are such as observing, classifying, describing, communicating, drawing conclusions, making operational definitions, formulating hypotheses, controlling variables, interpreting data and experimenting. Gott and Murphy (1987) have in the same line earlier suggested that science is about solving problems in everyday and scientific situations, where a problem is understood as a task with no immediate answer or routine method of solution. Whether practical or not, there are a set of procedures, which must be understood and used appropriately, including identifying the important variables, deciding their status (independent, dependent or control), controlling variables, deciding on the scale of quantities used, choosing the range and number of measurements, their accuracy and reliability, and selecting appropriate tabulation and display. These activities are often referred to as practical skills, and are often taught in isolation, which Gott and Mashiter account as circus-type experiments.

Instead Gott and Mashiter (1991, p. 61) applaud for a task-based approach.

To develop this they first clarify the distinction between processes and procedures, which they believe the lack of distinction of have caused much confusion. Procedures should be concerned with operations on variables (in a heuristic sense). Processes (as defined by Tobin et al. (1984)) should be concerned with different modes of thought or intellectual operations involved when solving problems encountered in science and, more generally, in everyday life situations. Therefore a process like controlling variables is also a procedure.

As for the case of Woolnough (1991b), Gott and Mashiter aim for a more holistic approach, where both procedural and conceptual understanding weld together. Curricula should be changed into a series of tasks with elements of motivation stemming from confidence in and a sense of ownership of the activity. This is what they call a *task-based approach.* They develop a model for the connection between conceptual understanding and procedural understanding (see figure 5.1, left).

They explain the model by:

> The *processes* are the various 'ways of thinking' that will be needed to co-ordinate the pupils' conceptual and procedural understanding into an overall plan for the task. As the task develops, they will *use and develop concepts* such as strength, force and deceleration *while utilizing and refining the procedural elements* of the task - the strategies of deciding what to vary, measure and control and how to do it effectively to give valid and reliable results.
>
> (Gott and Mashiter (1991), pp. 61-62, original emphasis)

They discuss what they see as the three most influential factors on determining the task difficulty: context, conceptual understanding and procedural understanding.

Context is seen as one of the most important determinants of pupil success. If a student is particular interested in a given context, then they will be motivated and knowledgeable in a task involving investigations within this context.

Conceptual understanding can be a missing factor in solving the task, if e.g. the students lack any conceptual understanding of the concept. The students should work with concepts with which they have some acquaintance.

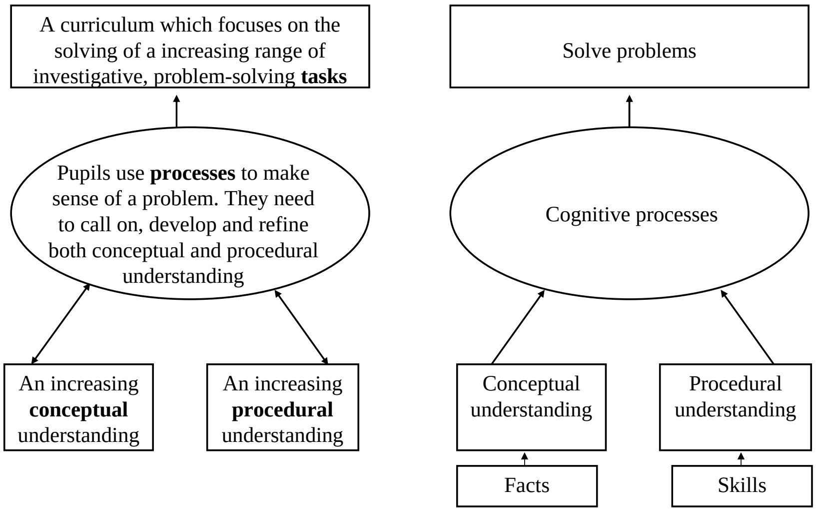
Third is the *procedural understanding*, the same case rests, but so far their is a lack of description of this understanding.

Taking of from this model and the refereed lack of a description of the procedural understanding, Gott and Duggan (1995) develop a model of science, both applicable to the whole of the science curriculum as well as to practical work. They base the model on the epistemological perspective which seeks to define what is to be taught and learned, rather than how that is to occur. The developed model can be seen at figure 5.1 (right).

To explain this model, first the entries are explained, starting from the bottom.

Facts are seen as associations between names, other symbols, objects and

Figure 5.1 Left: Processes mediate procedural and conceptual understanding in the solution of a task, as given by (Gott and Mashiter 1991, p. 62). Right: A model of science, as given by Gott and Duggan (1995, p. 25).



locations. These feed into the *conceptual understanding*, which is the understanding of concepts, where concepts are classes of objects or events that are grouped together by virtue of sharing common defining attributes, that is the facts, laws, theories and principles of science. Examples of concepts are energy, gravity, the laws of motion, heredity, solubility and photosynthesis.

Skills are understood as activities such as the use of measuring instruments and the construction of tables and graphs, which are necessary but not sufficient to carry out (most) practical work. " *Procedural understanding* is the understanding of a set of ideas which is complementary to conceptual understanding but related to 'knowing how' of science and concerned with the understanding needed to put science into practice." (Gott and Duggan (1995), p. 26, my emphasis.) They state, it is the thinking behind the doing. This set of ideas they develop into 'concepts of evidence'.

They define *cognitive processes* as the processes "...such as observing, classifying and inferring, that is the thoughts that go through scientists' minds as they perform practical science activities." (Gott and Duggan (1995), p. 19).

Within the developed model, "...cognitive processes needed to solve all kinds of problems, are seen as involving an *interaction* of 'conceptual' and 'procedural' understanding." (Gott and Duggan (1995), p. 25) and continue :

> The *cognitive processes* refers to the interaction involving the selection and application of facts, skills, conceptual and procedural understanding. These cognitive processes are the means of obtaining or processing the information needed to tackle a problem successfully.
>
> (Gott and Duggan (1995), p. 27)

This includes hypothesizing, interpreting, predicting etc.

Since the model is not describing only problems of a practical nature, *problem solving* is seen as any activity that require students to apply their understanding in a new situation, including explanation of phenomena, applied science problems, theoretical problems and investigations (which they have a special understanding of).

Gott and Duggan (1995) naturally discuss the intertwinements of conceptual and procedural understanding, and accept that they are not always separative. Still, they argue, envisioning them as two different understandings are helpful, especially since the procedural understandings are so poorly discussed in the previous literature. Gott and Duggan (1995, p. 27) also argue that procedural understanding has to be taught in order to make students able to perform the cognitive processes needed to solve problems.

Clearly this threefold argumentation for labwork activities are build around the idea that what is gained from labwork activities should both be of use in the physics classrooms, but more importantly it should build and shape the students engaged in the activities, providing them with a greater understanding and self-confidence of addressing the world.

Comparing these ideas with the curricula aims, such as presented in section 5.1.3, arguments related to the nature of science are not directly discussed. This is though taking up by Hodson, when discussing a three-fold aim of science education (including labwork activities) of learning science, learning about science, and doing science.

5.3.4 Learning science, learning about science, doing science

Hodson (1992 1993) argues how labwork activities are both over-used and under-used. The former since labwork activities are expected to meet all sorts of learning goals, and the latter, since its real potential is only rarely fully exploited. The way out of this dilemma is twofold; first one should be clear about the purpose of the particular lesson, and second to choose a learning activity that suits it. These ideas are quite similar to the model presented in section 4.6.2 about obstacle dislodgement.

Having argued against labwork aims such as they are presented in curricula

Hodson (1993, p. 106) defines three purposes of science education, and then interprets how these can be reached through practical work (though arguing how labwork should only be used when no alternatives are present, since labwork activities are potentially holding a lot of barriers for reaching the intended learning):

Learning science Acquiring and developing conceptual and theoretical knowledge;

Learning about science Developing an understanding of the nature and methods of science and an awareness of the complex interaction among science, technology, society and environment;

Doing science Engaging in and developing expertise in science enquiry and problem solving;

For the case of *learning science*, Hodson (1992, p. 67) argues how labwork should be used to provide opportunities for concrete illustrations and representations of previously taught abstractions. Often, he states, labwork activities work the other way around, where students are expected to distil the abstract from the concrete. As he states: “Theory should come first.” (Hodson (1992), p. 67). If not, potentially the students will keep on holding or developing new misconceptions instead. Also, these inductive labwork activities might invoke wrong ideas about the nature of science. As he states, labwork activities should be about exploring existing ideas, which has previously been theorized. Since many concepts in science can only be displayed indirectly (e.g. energy), Hodson pleas for more use of computer-based learning. Still, in line with Woolnough and Allsop (1985), he argues for labwork activities as the only way of gaining first hand experience with scientific phenomena.

Concerning *learning about science*, Hodson argues:

> A much more significant role for bench work concerns concept development, understanding the nature of scientific enquiry and the key issue of personalization of learning, as [. . .] constitutes both a complex prerequisite for engaging students in doing science for themselves and the educational outcome that justifies doing so.
>
> (Hodson (1992), p. 71)

Hodson argues how the process approach degenerates science into a discrete set of activities, and states

> Nothing could be further from the truth. In reality, doing science is an untidy, unpredictable activity that requires each scientist to choose a course of action that is appropriate to the particular situation. Success depends rather more on the ability of the scientist to analyse the whole situations, to think on several different levels simultaneously and to draw on fragments of theories and clusters of information in order to make contextually appropriate decisions, than on mastery of a clear set of principles and procedures to be carefully followed.
>
> (Hodson (1992), p. 73)

Labwork activities are reasonable ways of gaining this insight, especially in enquiry-based activities.

Finally, *doing science* is explained by "... using the methods and processes of science to investigate phenomena, solve problems and follow interests that learners have chosen for themselves." (Hodson (1992), p. 73) This, he argues, is not unproblematic, and to foster success some prerequisites should be hold: (1) possession of an appropriate conceptual background, (2) understanding of what scientific investigations involve, (3) ability to perform certain laboratory operations successfully, (4) experimental flair, and (5) an elusive, but strong, affective component involving confidence, commitment and determination. Hodson (1992) pleas for a holistic approach, but stating "The only effective way to learn to do science, then is by doing science" (Hodson (1992), p. 73).

As seen, Hodson (1992) is inspired by Woolnough and Allsop (1985), but has imbedded the *learning about science*-argument to also include nature of science besides understanding scientific methods. Though neither of the two presented three-fold divisions makes attitudes and affective arguments explicit, they are discussed and judged valid.

5.3.5 Competencies

Yet another way of discussing the normative issues of science education and especially practical work is through the concept of *competencies*, which has a great impact on the Danish rhetoric about mathematics and science teaching, but also exist in the Anglophone literature (AAPT 1997).

Scientific competencies are defined as "... to possess knowledge of, to understand, to exercise, to use and to critically be able to make up one's mind concerning nature, science and technology in the multiple relations, where these enter or could enter." (Andersen et al. (2003), p. 19, own translation)

In the publications concerning the future education in science in Denmark published by the Danish Ministry of Education (vision and strategy discussion (Andersen et al. 2003) and anthology (Busch et al. 2003)), the competence idea is thought to orchestra a move away from curriculum-driven teaching towards a more contemporary interpretation of the societal needs of its citizens, emphasizing "... transformation readiness, analytic sense, action competence, lifelong learning and cooperation skill." (Andersen et al. (2003), p. 19, own translation)

A more detailed description is needed to understand the scientific competencies, and the publication emphasises four sub-competencies:

Competence of empirical data Observation and description, experimentation, classification, manual skills, data collection and data treatment, safety, estimation of uncertainties and appropriateness, methods critique, generalization between practice and theory, ...

Competence of representation Symbols and representations, observe, present, distinguish and change between different representation levels, analyse, understand power of explanation, abstract, reduce, ...

Competence of modelling Formulate problems, set up, distinguish between model and reality, reduce, analyse, specify, use appropriate, verify, falsify, determine causality, criticize, develop, ...

Competence of putting into perspective Inner relations, relations with non scientific disciplines, historical/cultural relations, relations to the near and the distant outside world, reflect on the roles of science and technology in the development of society, critically estimate the knowledge of science in relations to other knowledge, ...

In the anthology publication, Dolin et al. (2003) give a first bidding on the description of the sub-competencies in the discipline of *physics*. This work is inspired by the PhD thesis work (Dolin 2002). The first four sub-competencies are more or less identical to the sub-competencies of science presented above, whereas the latter three are specific for physics, and as argued by the authors, they might be included in the first four, but it is found valuable to extract them for further analysis.

1. Plan, conduct and describe physical experiments
2. Work with different representations of physical phenomena
3. Build and analyse models
4. Put physics into perspective according to the discipline itself, other disciplines, theories of knowledge, historical development and itself
5. Use physical ways of thinking
6. Physical reasoning
7. Communicate in, with and about physics

The first sub-competence related to experiments are further described as to:

> ... use common occurring equipment, including computer devices for data collection and data analysis; estimate the reliability of the measuring equipment and the appropriateness of the method of investigation, including comments on sources of error and uncertainties; have an understanding of the connection between theory and experiment.
>
> (Dolin et al. (2003), own translation)

First should be noticed how the competence description place emphasis on the planning, conducting and describing (or reporting) the labwork in play, thereby stating how the conducting and reporting of labwork activities is not enough to gain experimental competencies. This could be interpreted as related to the 'doing science' or 'being a scientist', which the above presented authors talked about, but lacks the hypotheses making and identification of a problem, which is present in their descriptions.

Further the experimental competence of physics place emphasis on plain procedural skills, such as using equipment, but also advanced procedural skills, such as estimating the reliability of the method and the data. But also having an epistemological understanding of physical knowledge in understanding the relation between theory and experiment is emphasises. Relating this to the discussions in the previous sections, the first-hand experience with phenomena is missing, possibly because this is placed in the representation competence.

The competence description does not directly discuss the ability to approach problems with unknown solving strategies, confidence in own abilities and daring to go into unknown territory. The competence philosophy is though explicitly expecting to create an increased student motivation and interest.

5.3.6 Summary

As seen, strong correlation exist between the labwork aims found in curricula and the research literature (not surprisingly). The discussed aims for labwork activities could be summed up to:

1. Conceptual domain
2. Procedural domain
3. Scientific enquiry
4. Nature of science domain
5. Scientific attitudes domain
6. Affective domain

where the latter two might not be directly recognized in the referred, but easily found between the lines, when e.g. talking about motivating and interest, along with the confidence issue of making students feel confident in being able to approach scientific, empirical problems without having ready solution strategies.

Possibly, the understanding of the categories are not completely overlapping between the different actors, and the list has at least as many critics as followers. In the following, the five different argument domains are investigated in order to truly grasp what they contain, and to discuss the value of each of them, as these are presented by followers and critics.

5.3.7 Conceptual domain

In one way or the other, all researchers discussing the purpose of labwork, add the conceptual domain to their list of labwork aims: Shulman and Tamir (1973) called it 'concepts', and described it by the sub-categories of hypothesis, theoretical model and taxonomic category. Newton (1979) talks about 'didactic aims', understood as to clarify, order and extend experiences of natural phenomena, and to illustrate laws. Woolnough and Allsop (1985) talk about getting a 'feel for phenomena', understood as how school science is about getting acquainted with the physical world we live in and making sense of it along with building a reservoir of tacit knowledge. Hegarty-Hazel (1990c) talks about introducing a new discipline, providing for individual differences, providing concrete learning experiences. Tamir (1991) describes how practical experiences are especially effective in inducting conceptual change. Millar (1991) talks bout 'conceptual understanding' as the learning and understanding of science concepts (opposed to 'procedural understanding' as developing competence in the skills and procedures of scientific enquiry). Wellington (1994a) talks about 'to illuminate/illustrate ('first-hand' knowledge)' such as an event, a phenomenon, a concept, a law, a principle, a theory. Hodson (1993 1996) talks about learning science, understood as acquiring and developing conceptual and theoretical knowledge. Golin (2002) talks about labwork as a source of new knowledge which is later systematized and generalized. Goldbech and Paulsen (2004) talk about experiencing and observing phenomena in nature and in the lab along with learning the scientific concepts by observing them in a context.

In the list of labwork aims by Kerr (1963), a number of the items is related to the conceptual domain, such as: to elucidate the theoretical work so as to aid comprehension, to verify facts and principles already taught, to be an integral part of the process of finding facts by investigation and arriving at principles, and to make physical phenomena more real through actual experience. The same thing goes for the list by Boud et al. (1980): to illustrate material taught in the lectures, to teach some 'theoretical' material not included in the lectures, and to help bridge the gab between theory and practice. As shown in section 5.2 the conceptual domain does not draw the highest scores.

Critique of the conceptual domain

Even though the conceptual domain is on every list of purposes for labwork activities, it is probably also the most critiqued domain.

The conceptual domain has often been objected in two ways: One is that labwork activities cannot be used to teach students about the world of theories. Second, even if it could, there exist a number of other teaching-learning activities, which are more effective (and cheaper and less time-consuming) for reaching the same goals.

Poor learning outcomes of labwork activities in relation to the conceptual domain have been reported (reviewed in e.g. Hofstein and Lunetta (1982); Hodson (1986 1990)). Teaching conceptual knowledge through labwork activities might even cause a distorted view of science and the interplay between theory and experiment. Woolnough and Allsop (1985) describe, how during practical work students might come up with wrong theories, which are then rejected by the teacher, ending out teaching students to answer correctly based on books and the like instead of using what they see from the experiment. Problems in teaching conceptual knowledge through labwork activities are also identified in relation to alternative conceptions (Woolnough and Allsop 1985), since students see in-deliberately what they expect to see. The issues of pre-conceptions, they state, have to be taken carefully into account when doing labwork activities, and then practical work might successful alter the students alternative conceptions:

> First to ascertain and disentangle the relevant preconceptions the student is bringing to the laboratory, and secondly to modify them through discussion and possibly demonstration so that insights are taken into practical work which will enable a better sense to be made of what is seen.
>
> (Woolnough and Allsop (1985), p. 37)

Also, many problems arise because of the confusion between discovery and rediscovery (Woolnough and Allsop 1985, p. 37). Rediscovery is explained by learning science, meaning learning the accepted scientific wisdom, becoming closed, convergent and teacher-lead. Discovery, on the other hand, is essentially more open and divergent, but students are unlikely to discover the deep insights, which have taken more mature scientists years to reach. Also Millar (1998) argues against discovery over rediscovery: "... I will try to develop a rationale for practical work within a perspective which sees science education as the passing on of well-attested knowledge rather than a personal enquiry leading to the 'construction' of knowledge." (Millar (1998), p. 17). Hodson (1992) concurs with this argument by referring to the theories of Piaget, stating that practical work often deals with specific materials, which are to be used to give general statements about all materials, which is not possible understood by those, who have not gained the Piagetian stage of formal operations; whereas those who *have* moved to this stage have no need of concrete examples.

Finally, the imposition of theory on practical work has had a detrimental effect on the development of scientific investigations, but also that the imposition of practical work on theory has had a detrimental effect on the development of cognitive understanding (Woolnough and Allsop 1985, p. 38). This lead to the plea that practical work should deliberately and consciously be separated from the constraint of teaching scientific theory. There are self-sufficient reasons for doing practical work in science. Naturally, there are important links that can and should be made between practical work and theory.

Woolnough (1991a) discusses how aiming labwork activities for enhancing the students' understanding of the theories of science often result in cookbook instructions to make sure the students develop 'the right theory'. Evidence shows that this method enhances little understanding of the concepts of science and nothing of applications of the methods of science.

Understanding the conceptual domain

I concur that a limited understanding of the conceptual domain can easily be used as an argument against setting this as a purpose of labwork activities, but when digging into the complexity of the conceptual domain, a number of arguments reveals, making the argument valid.

The most prominent argument for the using the conceptual domain as a valid argument for labwork activities is through the creating of a long-term memory storage of experiences of relevant physics phenomena.

This argument is found by a number of authors. Hodson (1992) argues, that practical work should be used to giving concrete illustrations and representations of the abstract concepts, priory taught. Computer-based 'playing with scientific concepts' is a good way to work with the concepts, which is not directly observable, but still there are things, that computer programs can not provide students with. These are what Woolnough and Allsop (1985) call 'getting a feel of phenomena', such as getting acquainted with the smell of a gas or the attraction and repulsion of a magnet. White (1991) even argues that this is the principal purpose of labwork activities.

Woolnough and Allsop (1985) put forward the distinction between *explicit* and *tacit* knowledge, where explicit knowledge is regarded as the 'correct' scientific knowledge, such as it is written in textbooks. Tacit knowledge is explained by the analogy of the knowledge hold in order to ride a bike. Explicit knowledge is what labwork activities are wrongly expected to teach the students, possibly causing a distorted image of science since, as they state, scientists mostly operate with tacit knowledge. They state that we need to emphasize the value of both explicit knowledge and tacit knowledge in teaching. Practical works might not be ideal to teach explicit knowledge, but practical work is a way to gain tacit knowledge.

Atkinson (1990) has in the book edited by Hegarty-Hazel written a chapter on learning scientific knowledge in the student laboratory. She also talks about tacit knowledge, which she explains through the concept of long-term memory storage. She divides long-term memory into semantic and episodic memory, where semantic learning is

> ...the organized knowledge a person possesses about words and other verbal systems, their meaning and referents, about relations among them, and about rules, formulae, and algorithms for the manipulation of these symbols, concepts and relations.
>
> (Atkinson (1990), p. 122)

Episodic memory is memories of events, either witnessed (as demonstration practical works) or as an active participant (as student practical works).

Atkinson emphasis enhanced scientific learning by moving away from teacher demonstrations to student laboratories. Further a number of strategies is quoted to promote better learning of conceptual learning, both within and outside practical work (Atkinson 1990, p. 129):

1. Initial exposure of students' alternative conceptions through their responses to an 'exposing event';
2. Sharpening student awareness of their own and other students' alternative conceptions through discussion and debate;
3. Creating conceptual conflict by having students attempt to explain a discrepant event;
4. Encouraging and guiding cognitive accommodation and the invention of a new conceptual model consistent with the accepted scientific conception.

Other ways are pre-questionnaire exploring the meaning of words associated with the practical work, making students do predictions beforehand, asking students to choose a metaphor to describe their thoughts or ideas about a piece of scientific knowledge. This idea is further elaborated by Gunstone (1991b), talking about POE (**P**redict - **O**bserve - **E**xplain).

My view

Both Atkinson and Woolnough and Allsop are critical towards teaching students scientific or conceptual knowledge through labwork activities, especially if the conceptual knowledge is understood as the 'correct' scientific knowledge, such as displayed in science books.

Instead labwork activities should be used to teach another type of conceptual knowledge. Woolnough and Allsop call this type for tacit knowledge and is related to getting a feel for phenomena, and Atkinson talks about a long term memory storage. This tacit knowledge or memory storage is important in order to be able to argue for or against various theoretical ideas. E.g. when students discuss force and acceleration in relation to writing on a bike (as seen in Schilling (2007)), they make use of their own tacit knowledge or memory storage concerning force and acceleration. But for a number of physical concepts (e.g. radioactivity), the students have no tacit knowledge about this concept from their everyday life, and labwork activities is a prominent way to gain this feel for the phenomena in play.

While Woolnough and Allsop talk about their tacit knowledge as mainly getting a feel for phenomena, Atkinson unfolds her concept of memory storage into a semantic and an episodic memory. The episodic memory is exactly to gain a feel for phenomena. The semantic memory is the long-term memory of words, symbols, numbers, equations, algorithms and their relations, in order to articulate, operate and manipulate the episodes.

It is reasonable to argue how labwork activities are the most prominent way to gain an episodic memory, whereas the semantic memory might be equally well developed by other teaching activities.

5.4 Procedural skills domain

It is not completely obvious where the line should be drawn between the skills domain and the enquiry domain, and authors use the word differently.

Shulman and Tamir (1973) talk about skills as aims of labwork activities, and describe them as e.g. manipulative, enquiry, investigative, organizational, and communicative. Newton (1979) talks about skills as the use of apparatus, specific manipulative skills, standard techniques, comprehension and execution of instructions, communication of results, and conclusions. Hellingman (1982) talks about labwork activities as being able to develop psycho-motor abilities. Højgaard Jensen (2002) talks about labwork activities as a means to learn measuring techniques, data treatment, calculating with units and to gain understanding of uncertainties. Woolnough and Allsop (1985) talk about developing practical scientific skills and techniques, described as observing (carefully, honestly and perceptively), measuring, estimating, manipulating, recognizing similarities and differences, appreciating what is significant, being able to measure a variety of properties, using scientific instrument (where human senses are lacking), estimating values for physical quantities, making sensible approximations, handle apparatus and equipment safely and appropriate, develop appropriate experimental techniques, planning, executing and interpreting the results, manipulating and making sense of data, and appreciating the extent of its reliability. Wellington (1994a) talks about skills as practical techniques, procedures, 'tactics', investigation strategies, working with others, communicating, and problem-solving. Goldbech and Paulsen (2004) talk about developing practical and observational skills (which develops skills in reasoning and argumentation.

Kerr (1963) has on his list two labwork aims related to skills: To encourage accurate observation and careful recording, and to develop manipulative skills. Boud et al. (1980) list how labwork activities might teach basic practical skills, to familiarize students with important standard apparatus and measurement techniques, to train students in observation, to train students in making deductions from measurements and interpretations of experimental data, to train students in writing reports on experiments, to train students in keeping a day-to-day laboratory diary, and to train students in simple aspects of experimental design.

5.4.1 Critique of the procedural skills domain

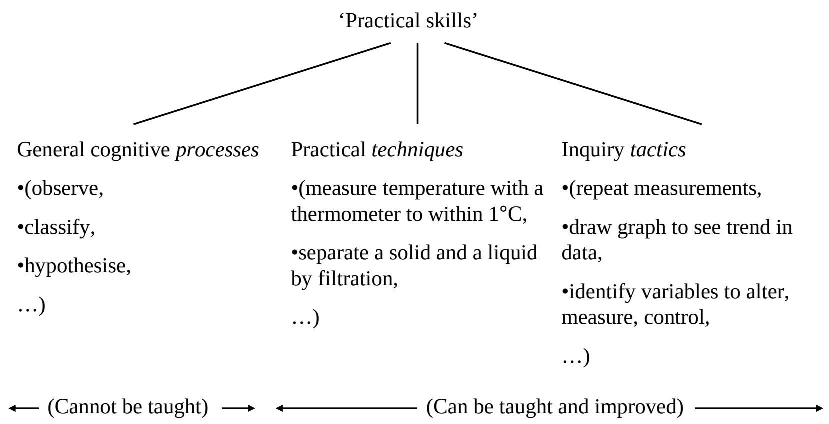
Shulman and Tamir (1973) quote a survey of year 8 biology pupils (Yager et al. 1969), where students of three classes have been exposed to three different working styles: a laboratory class, where the students individually or in groups performed a large number of experiments; a demonstration class, where the students were shown the same experiments as demonstrations; and a discussion class, where the students did not see or perform any experiments, but worked with analyzing, interpreting and concluding based on results, a long with discussions of experimental designs. “On the basis of the research findings it was concluded that the laboratory approach provided no measurable advantages over other modes of instruction except in the development of laboratory skills.” (Shulman and Tamir (1973), p. 1120).

Though Woolnough and Allsop (1985) plea for skills as one of three purposes of labwork activities since these skills and techniques are important for scientists, and should therefore be developed in the school setting, they still pose critical questions. They understand skills as apparatus handling, observing and measuring, and planning, executing and interpreting experiments. The first - apparatus handling - is obviously taught and learned doing practical work, but how beneficial is it anyway? For the more complex skills, surveys have shown that students at the age of 15 have not gained the more developed skills of observing and measuring and even less of planning, executing and interpreting.

In line of transferability, Woolnough (1991c, p. 7) discusses done research, showing poor outcome of the transferability of skills, such as using a microscope and plotting of a graph. Also more general skills such as planning, observing, interpreting and inferring have not proven to serve transferable. Woolnough believes the most important (and maybe the only) transferable skill, is that of self-confidence.

Hodson (1990) argues against laboratory skills as an argument for labwork activities. Laboratory skills seem not to be a goal in itself, and often student have not even gained the laboratory skills. Two kinds of laboratory skills are discussed: content-free, generalisable, transferable skills that are of value to all; and basic craft skills, which are only of interest for the few proceeding with a career in science. The first argument borders the absurd, he states, because which practical skills are transferable and of value to all? The latter, he claims, is meaningless. At the same time, studies have shown that a large number of students did not gain the skills, which the practical work was designed to give them. But, Hodson states, it can be a means to further learning. The situation of practical work demands some laboratory skills among the students, so if practical work should be used as a learning method, laboratory skills are necessary. But their necessity should be questioned, and if found useful, they should be incorporated properly. Hodson (1992) states, where practical work is deduced to data collection and no reflection on the scientific concepts involved, the teaching methods lead to failure. A student lacking appropriate theoretical understanding will not understand the purpose of the practical work, and will in the best case look for the wrong results, and even worse the labwork experience will confirm the misconceptions. Hodson (1992) also argues that the skills of science is not to be able to operate a certain piece of equipment, but to know the *processes of science*, such as hypothesizing, inferring, designing experiments

Figure 5.2 Millar's model for practical skills.



and interpreting data.

Højgaard Jensen (2002) states how labwork activities as a way to train skills, - like measuring techniques, data treatment, calculating with units or to gain understanding of uncertainties - are useful, but might be trained even better in other school disciplines.

5.4.2 Understanding the procedural skills domain

According to Millar (1991), research lacks a model of procedural understanding, such as already existing for conceptual understanding in many domains of science, and therefore he develops a model of how to understand practical skills in science labwork activities, by dividing them in three: *General cognitive processes*, *practical techniques* and *enquiry tactics*, as seen at figure 5.2.

General cognitive processes are e.g. observing, classifying and hypothesizing. These processes are often highlighted by curriculum makers, especially those believing in the 'skills and process approach'. General cognitive processes, according to Millar *should not* be taught, *cannot* be taught, and *need not* be taught:

> . . . it is misleading and unhelpful to portray the 'method of science' as a set of

> discrete processes; and second, that most of the so-called 'processes of science' are general cognitive skills which all humans routinely employ from birth, without formal instruction, so that it is absurd to claim that these can (or need) in any sense to be *taught* or *developed*.
>
> (Millar (1991), p. 45)

He continues:

> The challenge for science education is not to develop or to teach these processes. It is to present science in such a way that children feel that it is personally valuable and worthwhile to use the cognitive skills which they already possess to gain an understanding of the scientific concepts which can help them make sense of their world. [...] Effective teaching in science requires that we develop activities which motivate and encourage children to make *use* of their skills of observing, classifying, hypothesizing and predicting as a means of exploring and coming to an understanding of scientific ideas and concepts. The confusion at the heart of the process approach is between *means* and *ends*. The processes are not the ends or goals of science but the means of attaining those goals.
>
> (Millar (1991), p. 50)

Practical techniques, like measuring temperature with a thermometer to within 1 degree or separating a solid and a liquid by filtration, can on the other hand be taught and improved. These are specific pieces of know-how about the selection and use of instruments along with knowledge of how to carry out standard procedures.

Inquiry tactics are e.g. repeating measurements, drawing graphs to see trends in data, and identifying variables to alter, measure and control, and can be taught and improved. This is seen as toolkit of strategies and approaches, which can be considered in planning an investigation.

Progression is possible within this model, as practical techniques and enquiry tactics can be increasingly complex. Labwork activities in schools are holding the potentials to teach students both practical techniques (which are needed for doing labwork activities, but rarely can be seen as a goal in itself (Hegarty-Hazel 1990a)) and enquiry tactics, which are valuable both within the science class and outside.

Using the three-fold division of procedural understanding developed by Millar (1991) it becomes clear how especially enquiry tactics are a relevant and valid goal of labwork activities. Therefore it is needed to find a further development of enquiry tactics in order to pair those with done labwork activities. E.g. Gott and Duggan (1995 1996); Golin (2002) go into details about enquiry tactics (though naming them differently).

Gott and Duggan (1995) develop a model of science, where procedural and conceptual understandings emerge to cognitive abilities, leading on to the competence of solving problems (see section 5.3.2). As also Millar (1991) stated, the conceptual understanding has long been investigated in science education research, but as Gott and Duggan argue, the procedural understandings are under-researched. To develop this understanding they find use in Bloom's taxonomy of 'educational objectives for the cognitive domain' (Bloom 1956), which they equal their conceptual understandings. On this basis they develop a mirrored 'procedural understanding'. The resulting taxonomies for the conceptual and procedural understandings can be found in table 5.5.

Table 5.5 Description of the conceptual and procedural understandings, as given by (Gott and Duggan 1995, p. 29).

Conceptual taxonomy	*Procedural taxonomy*
Knowledge and recall of facts	Knowledge and recall of skills
Understanding of concepts	Understanding of concepts of evidence
Application of concepts (in unfamiliar situations)	Application of concepts of evidence (in unfamiliar situations)
Synthesis of concepts (in problem-solving)	Synthesis of concepts of evidence (in problem-solving)

As seen, they base their procedural taxonomy on skills and 'concepts of evidence', being complementary to facts and concepts. Here it is needed to clarify what is meant with concepts of evidence. They structure

> ... these concepts of evidence around the four main stages of investigative work: namely, those concepts associated with the design of the task, measurement, data handling and, finally but crucially, the evaluation of the complete task in terms of the reliability and validity of the ensuing evidence.
>
> (Gott and Duggan (1995), p. 30)

They now turn to the application of the taxonomy concerning the procedural understanding For the first entry in table 5.5 'knowledge and recall of skills' examples are such as the use of thermometers (identical to Millar's practical techniques). For the 'understanding of concepts of evidence', examples are an understanding of the role of the fair test (control of variables) within a familiar context, or the range and number of readings required in measurements of temperature (identical to Millar's enquiry tactics). The concepts of evidence should also be applied to novel situations (transferred), where as an example they withdraw again the fair test, which pupils should be able to apply in a whole range of circumstances, including both all critical works and to critically evaluate other people's experiments. Finally the 'synthesis of skills and concepts of evidence in problem solving' can be exemplified in linking fair tests and the validity of any resulting data, or between the accuracy of a set of readings and the reliability of the data.

When talking about the concepts of evidence, they develop an entire list of these. These 'concepts of evidence' make up a list of explaining Millar's enquiry tactics, see table 5.6.

Table 5.6 'Concepts of evidence' by Gott and Duggan (1995), used to understand Millar's enquiry tactics.

Associated with design	
Variable identification	Understanding the idea of a variable and identifying the relevant variable to change (the independent variable) and to measure, or assess if qualitative (the dependent variable)
Fair test	Understanding the structure of the fair test in terms of controlling the necessary variables and its importance in relation to the validity of any resulting evidence
Sample size	Understanding the significance of an appropriate sample size to allow, for instance, for probability or biological variation
Variable types	Understanding the distinction between categoric, discrete, continuous and derived variables and how they link to different graph types
Associated with measurement	
Relative scale	Understanding the need to choose sensible values for quantities so that resulting measurements will be meaningful. For instance, a large quantity of chemicals in a small quantity of water causing saturation, will lead to difficulty in differentiating the dissolving times of different chemicals
Range and intervals	Understanding the need to choose sensible range of values of the variables within the task so that the resulting line graph consist of values which are spread sufficiently widely and reasonable spaced out so that the 'whole' pattern can be seen. A suitable number of readings are therefore also subsumed in this concept
Choice of instrument	Understanding the relationship between the choice of instrument and the required scale, range of reading required, and their interval (spread) and accuracy
Repeatability	Understanding that the inherent variability in any physical measurement requires a consideration of the need for repeats, if necessary, to give reliable data
Accuracy	Understanding the appropriate degree of accuracy that is required to provide reliable data which will allow a meaningful interpretation
Associated with data handling	
Tables	Understanding that tables are more than ways of presenting data after they have been collected. They can be used as ways of organizing the design and subsequent data collection and analysis in advance of the whole experiment
Graph type	Understanding that there is a close link between graphical representations and the type of variable they are to represent. For example, a categoric independent variable such as surface, cannot be displayed sensibly in a line graph. The behaviour of a continuous variable, on the other hand, is best shown in a line graph
Patterns	Understanding that patterns represent the behaviour of variables and that they can be seen in tables and graphs
Multivariate data	Understanding the nature of multivariate data and how particular variables within those data can be held constant to discover the effect of one variable on another
Associated with the evaluation of the complete task	
Reliability	Understanding the implications of the measurement strategy for the reliability of the resulting data; can the data be believed?
Validity	Understanding the implications of the design of the validity of the resulting data; an overall view of the task to check that it can answer the question

For a less developed understanding of enquiry tactics, Golin (2002) list 7 tactics, which he names methodological skills:

- Describe the performed experiment of observation;
- Discriminate between primary and secondary outcomes in the experiment;
- Knowing the difference between the expected and the observed data;
- Predict the future development of further experiments;
- Tabulate the data obtained, plot diagrams and 'interpret' them;
- Putting forward a hypothesis to account for experimental results;
- Constructing an additional experiment to confirm or refute the hypothesis suggested;

As seen, some overlaps occur between Millar's enquiry tactics, Golin's methodological skills, and Gott and Duggan's concepts of evidence.

These enquiry tactics categories will be discussed to a much higher extent in chapter 6.

5.4.3 My view

Shulman and Tamir (1973) had a category which they called *skills*, which included the headlines of manipulative, enquiry, investigative, organizational, communicative etc. I found that these were very varying in their nature, but when reading Millar (1991), it became clear how to categorize them and understand their inter-correlatedness. By use of Millar's model, the enquiry tactics are clearly valid aims for labwork tasks, since they are of use both in relation to vocational reasons, but more importantly has 'general education'-related values. But taking of from Millar a clarification and development of the enquiry tactics are needed. Here especially Gott and Duggan's 'concepts of evidence' fulfil the need.

I am fond of his threefold division, but again reading the category by Shulman and Tamir (1973), the communicative domain is missing. Therefore I operate with four subcategories within the procedural domain: General cognitive processes, practical techniques, enquiry tactics and communicative skills.

Also, when looking towards the concepts of evidence by Gott and Duggan (1995), there seems to be something missing. Therefore these enquiry tactics or concepts of evidence should include the sub-skills found in table 5.7 to table 5.6.

In relation to the uncertainties, additional enquiry tactics of error analysis could be included under the headline of 'associated with data handling', but as error analysis and the mathematical apparatus behind statistics is not a part of the curriculum, these are left out. Though not being able to operate the mathematical apparatus of error analysis, uncertainties can and should be understood in relation to the done labwork activities.

Table 5.7 Additional sub-skills to Gott and Duggan's 'concepts of evidence' to cover Millar's enquiry tactics.

	Associated with measurement
Uncertainties	Understanding the difference between systematic and random uncertainties, and how they affect the accuracy. Understanding how systematic uncertainties cannot be reduced by repeating the same experiment
	Associated with data handling
Units	Understanding and being able to include units in the data handling
Equation translation	Being able to translate between the mathematical expression gained from a fit procedure to an equation containing the relevant physics quantities (including units)
	Associated with the evaluation of the complete task
Uncertainties and errors	Understanding the effect of the uncertainties embedded in the measurements on the reliability of the results. Understanding the accuracy of the found results in relation to uncertainties. Understanding the concept of significant digits

5.5 Domain of scientific enquiry

There is no clear-cut division between procedural skills and the domain of scientific enquiry. Some discuss the division between processes and procedures (Gott and Mashiter 1991) or process skills and procedural understanding Warwick et al. (1999). For some problem-solving is synonymous with enquiry, and for others problem-solving means to solve standard tasks, which are strongly guided, designed for making students go through the intended solution algorithm. Therefore the concepts of skills, processes, procedures and enquiry are somewhat intertwined.

Another potential confusion is recognized by Woolnough and Allsop (1985, p. 6). Investigating the term 'being a scientist for a day' as synonymous with scientific enquiry, they review how different people put different things into the idea of being a scientist: The Baconian model of proceeding by induction is very different from Popper's ideas of hypothesis testing and falsification, which again is different from the discovery tradition and guided discovery found at Armstrong, Rousseau, Dewey and Bruner. Finally the model of scientist perceiving science as a craft activity, as articulated by Polanyi, stating 'a scientist must be an accomplished craftsman, having undergone a apprenticeship, learning how to do things without (always) being able to appreciate why they work'.

The idea of scientific enquiry as part of teaching science can be traced back to the early days of school laboratories (Huxley 164; Dewey 1910 1916), and the emphasis on enquiry in science teaching is one of those swing positions, which can be detected throughout the history of school laboratories, see section 5.1.1.

Shulman and Tamir (1973) talk about skills as also including enquiry (e.g., manipulative, enquiry, investigative, organizational, communicative) and cognitive abilities e.g., critical thinking, problem solving, application, analysis, synthesis, evaluation, decision making, creativity. Schwab (1974) discusses scientific enquiry under the headline of syntactic knowledge. Gott and Murphy (1987) suggest that science is about solving problems in everyday and scientific situations, where a problem is a task with no immediate answer or routine method of solution. Gott and Mashiter (1991) discuss the aims of labwork activities to be among others to process science (different modes of thought or intellectual operations involved when solving problems encountered in science and, more generally, in everyday life situations) and a procedural approach to open-ended investigative work. Millar (1991) talks about procedural understanding as developing competence in the skills and procedures of scientific enquiry. Woolnough and Allsop (1985); Woolnough (1991a) talk about being a problem-solving scientist through PRIME (**P**roblems to be tackled, **R**esearch into the appropriate factors, **I**deas about ways of attacking the problem, **M**aking the device or experiment, **E**valuating the outcome) - problems related to being a problem-solving scientist are open-ended, divergent and have no predetermined fact or theory. Hodson (1993) talks about doing science, as to engage in and developing expertise in science enquiry and problem solving. Wellington (1994a) discusses skills as also including problem-solving. Trumper (2002) talks about how we wish our physics students in upper secondary school and at universities to think like physicists, demanding the students having an understanding of the scientific methods of enquiry and being able to use these methods in their own investigations. Højgaard Jensen (2005) talks about labwork activities as an entrance to gaining competencies in experimental problem solving (understanding of and training in solving problems by attaching them in an empirical/experimental way.)

5.5.1 Critique of the enquiry domain

Two of the main spokespersons of enquiry and 'being a scientist' are Woolnough and Allsop (1985). When working towards a rationale and a framework for practical work they discuss the goal of science education and states that:

> We [...] would see students as scientists in their natural way of working; each naturally motivated to explore their world and to seek to interpret it for themselves and then make sense of it. [...] Our aim, therefore, to develop the scientist in the student should be seen as a general educational rather than a vocational one.
>
> (Woolnough and Allsop (1985), p. 32)

Woolnough and Allsop (1985) describe the rationale of science as letting the students be scientists, and expect problems of motivation to vanish by allowing the students to work in their own natural way. Even though science is in a sense public knowledge, students still need actively to construct their own personal awareness and meaning. They describe the nature of science as taking the two stands of scientific knowledge and problem-solving processes, and they see science as a problem-solving activity.

History has proved how enquiry learning is not an easy task to pursue, and often the enquiry ideas of curricula makers have been interpreted quite different by the performing teachers. E.g. Woolnough (1991a) states how labwork activities aim for developing students' ability to do practical problem-solving science (work as scientists), often results in exercises developed to enhance scientific skills rather than complete investigations.

Hodson (1990) discusses fundamental issues concerning enquiry learning preventing this type of learning to be problematic: "The suggestion that children can readily acquire new concepts by engaging in unguided and open-ended discovery learning activities is absurd." (Hodson (1990), p. 37). Firstly, he states, the purpose is not to discover a theory but to rediscover it; there *is* a real answer. Secondly, this is not the scientific way to do work either. So both pedagogical and epistemological problems exist in enquiry learning.

To outline his arguments against discovery learning, Millar (1998) states:

> Parallels with the activity of 'real scientists' in research laboratories are unhelpful and may be misleading. There are no necessary parallels between the way in which a piece of knowledge was first established and the way it is best communicated to someone who doesn't yet know it.
>
> (Millar (1998), p. 30)

5.5.2 Understanding the enquiry domain

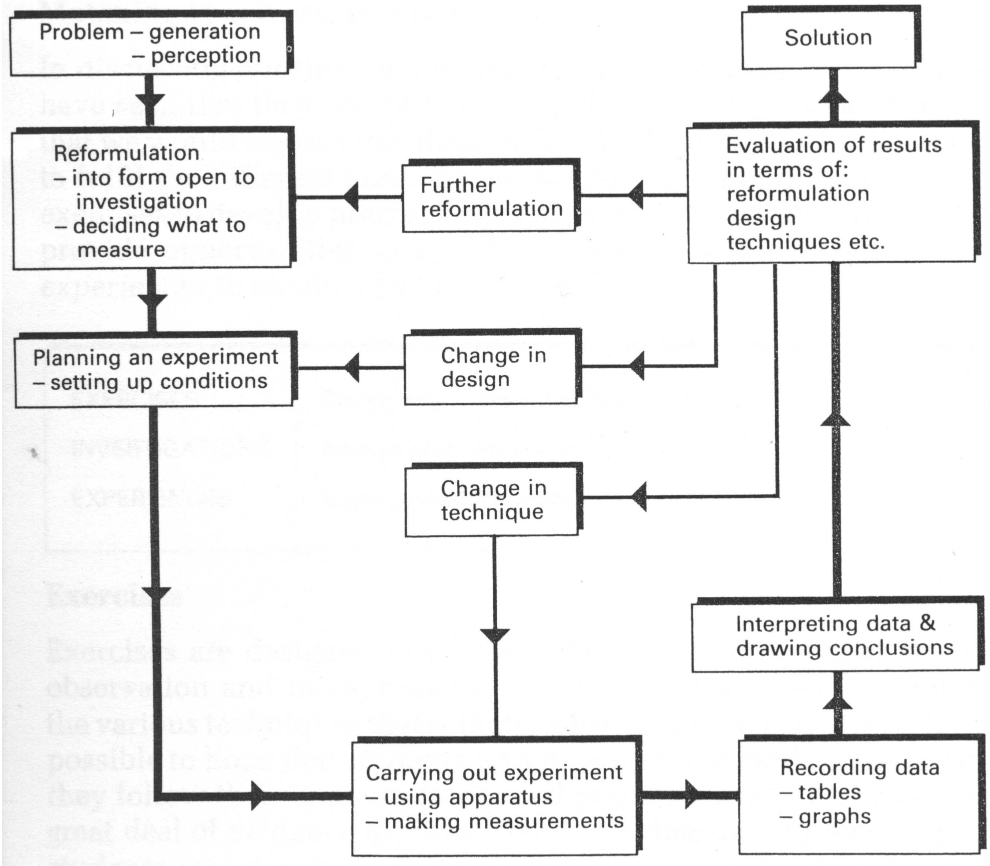
Woolnough and Allsop (1985) explain their labwork aim of being a problem-solving scientist by the acronym PRIME. This process of solving a problem as a problem-solving process is explained by through figure 5.3, baring close resemblance with the mathematical modelling circle, such as developed by Blomhøj and Kjeldsen (2006) for mathematics education.

Often the labwork activities are only incorporating carrying out the experiment, recording data and interpreting data and drawing conclusions, which is actually only half of the enquiry process. Processes are missing both before and after, namely the recognition or generation of a problem, reformulating it to a investigative problem and planning a setup, and after the evaluation of the results in terms of the latter processes of reformulation, design and carrying out, and finally answering the problem posed.

Klopfer (1990) has written a chapter entirely dedicated to scientific enquiry in the book about labwork activities edited by Hegarty-Hazel. Here he uses the term of scientific enquiry as the key term when talking about practical work. He states,

> Virtually all science teachers recognize that empirical enquiry is the hallmark of

Figure 5.3 The problem-solving chain, as given by Woolnough and Allsop (1985, p. 45).



the natural sciences. We believe that the sciences have succeeded in reducing human ignorance and building understanding largely because of their commitment to forms of enquiry which appeal to experimental and observable evidence to test ideas. One important challenge of science teaching at every educational level is to convey a firm sense of the nature and functions of empirical enquiry to our students. Engaging students in science laboratory activities and having them reflect on their work can contribute to meeting that challenge.

(Klopfer (1990), p. 95)

Klopfer defines *enquiry* by:

. . . enquiry is taken to be a general process by which human beings seek information or understanding. Broadly conceived, enquiry is a way of thought. Scientific enquiry, a subset of general enquiry, is concerned with the natural world and is guided by certain beliefs and assumptions. Scientists' beliefs about scientific enquiry and the assumptions underlying it tend to change over time, and the examination of these beliefs, assumptions and changes is the province of the philosophy of science.

(Klopfer (1990), p. 96)

Klopfer divides what is to be taught in science lessons into two: the content of science, which he describes as the body of structured knowledge about the natural world; and the *processes* of science, its methods of enquiry. He further divides the domain of scientific enquiry into three components: students' *science process skills* (observing and measuring, seeing and seeking solutions to problems, interpreting data, generalizing, and building, testing, and revising theoretical models); *general enquiry processes* (strategies, such as problem-solving, uses of evidence, logical and analogical reasoning, clarification of values, decision-making, and safeguards and customs of enquiry); and *the nature of scientific enquiry* (essentially epistemological, reflecting on its connections with the philosophy of science, e.g. that the structure of scientific knowledge is tentative - the product of human efforts - affected by the processes used in its construction and by the social and psychological context in which the enquiry occurs. Scientific knowledge is also affected by assumptions about the natural world, such as causality, non-capriciousness, and intelligibility).

The general enquiry processes are identical to the Millar's general cognitive processes, which he presses forward are developed from birth and not to be taught in science classrooms. The nature of scientific enquiry is discussed in the next section about the domain of nature of science. But Klopfer's science process skills bare the heart of empirical enquiry, potentially having some overlaps between Millar's enquiry tactics, as these are interpreted by Gott and Duggan's concepts of evidence.

Klopfer outlines five outcomes of scientific enquiry (students' science process skills), both concerning 'hands-on' aspects and reflective aspects, see table 5.8.

Here should be noticed, how Klopfer place more emphasis on the entire problem-solving chain, whereas Gott and Duggan operated primarily on the middle parts of the chain. Especially the 'ability to ask appropriate scientific questions and to recognize what is involved in answering questions via laboratory experiments' operates on the very first part of the chain of posing a problem or hypothesis to be investigated and the reformulation into an empirical investigation. Also the last 'ability to recognize the role of laboratory experiments and observations in the development of scientific theories' operates outside Gott and Duggan's field, when reflecting on the last processes of the problem-solving chain.

Klopfer (1990) describes table 5.8 of outcomes and student behaviour by

> ... how observation and experimentation, as well as hefty doses of careful thought and human interactions, contribute to the empirical enquiry process of theory-building. But what working scientist find most satisfying when they build and successfully test a good theory - and science students can share the feeling when they develop scientific theories - is that it lets them cover and relate and explain a whole range of phenomena in a concise yet comprehensive way.

Table 5.8 Klopfer's outcomes of scientific enquiry.

Category and description
The skills to gather scientific information through laboratory work • Observing objects and phenomena. • Describing observations using appropriate language. • Measuring objects and changes. • Selecting appropriate measuring instruments. • Processing experimental and observational data. • Developing skills in using common laboratory and field equipment. • Carrying out common laboratory techniques with care and safety.
The ability to ask appropriate scientific questions and to recognize what is involved in answering questions via laboratory experiments • Recognizing a problem. • Formulating a working hypothesis. • Selecting suitable tests of a hypothesis. • Designing appropriate procedures for performing experimental tests.
The ability to organize, communicate, and interpret the data and observations obtained by experimentation • Organize data and observations. • Presenting data in the form functional relationships. • Extrapolating, when warranted, of functional relationships beyond actual observations, and interpolating between observed points. • Interpretation of data and observations.
The ability to draw conclusions or make inference from data, observations, and experimentation • Evaluating and hypothesis under test in the light of observations and experimental data. • Formulating appropriate generalizations, empirical laws or principles that are warranted by the relationships found.
The ability to recognize the role of laboratory experiments and observations in the development of scientific theories • Recognizing the need for a theory to relate different phenomena and empirical laws or principles. • Formulating a theory to accommodate known phenomena and principles. • Specifying the phenomena and principles which are satisfied or explained by a theory. • Deducing new hypotheses from a theory to direct observations and experiments for testing it. • Interpreting and evaluating the results of the experiments to test a theory. • Formulating, when warranted by new observations or interpretations, a revised, refined, or extended theory.

(Klopfer (1990), p. 112)

According to Trumper (2003, p. 647), Klopfer (1990) is following Ausubel's line of 'guided discovery' in emphasizing that science teachers have the responsibility of helping students to understand the nature of scientific enquiry.

5.5.3 My view

The idea about scientific enquiry as the main aim of labwork activities is beautiful, but also problematic. Especially, if enquiry is interpreted as theory-free.

The pilot investigation of PE physics showed me that engaging unprepared students into scientific enquiry make them feel cheated, as if the didactical contract they share with the teacher was broken.

As discussed in the quote by Millar at page 169, taking the role of a scientist unveiling a new piece of knowledge is not necessary the best way of learning that piece of knowledge. But the enquiry domain is not about learning conceptual knowledge, but learning about scientific enquiry, that is to be able to operate the entire problem-solving chain. I favour students should be able to have insight into and being able to perform simple scientific investigations in order to make them feel less alienated by the natural world. Højgaard Jensen (2002) has explained it nicely with an example of his daughter, who came home and told how one can tell if a pregnant woman is carrying a girl or boy baby on the basis of the swings of a ring in a string placed over the stomach. Students should be able to make a simple investigation testing the validity of this claim, e.g. by repeating the experiment, making a blind experiment, etc. And having performed scientific enquiry help students to be critical to all their sources, both relating to science, and also other types of presented information. A necessity is that the task is presented with exactly this aim.

Using the science process skills of Klopfer (1990) and the problem-solving chain help to be clear about the aim of an enquiry labwork, both for the teacher and the students.

To be able to approach a problem with an open mind is beneficial for all students, both in relation to the learning of physics, other school disciplines and in their life outside school. Enquiry labwork activities are a nice entry into approaching and solving problems, to let the students gain a fell of success and confidence in their own abilities.

In other words

> If we can leave our students with a sense of self-confidence in their ability to tackle scientific problems and have stimulated them by the fun and challenges of science, we will have equipped them with vision and a pair of stout walking boots well prepared to deal with the next unexpected challenge.
>
> (Woolnough (1991b), p. 188)

But one should not be blind towards the many potential cul-de-sacs of enquiry labwork activities. It is important to invite the students into the right game in order to make them play.

Finally, several authors have warned about teaching labwork activities for enquiry aims without theory, which indicates a problematic idea of science (Hodson 1992; Wellington 1989b).

5.6 Nature of science domain

The ideas about nature of science and the epistemology of science came to be seen as important somewhat later than the procedural and conceptual domains. These days it can be seen in the boom of research done on nature of science in all corners of science education research (see section 2.2).

Shulman and Tamir (1973) talk about understanding the nature of science as e.g. the scientific enterprise, the scientists and how they work, the existence of multiplicity of scientific methods, the interrelationship between science and technology and among the various disciplines of science. Hodson (1993) uses the labwork argument of 'learning about science', understood as developing an understanding of the nature and methods of science and an awareness of the complex interaction among science, technology, society and environment. Goldbech and Paulsen (2004) talk about the understanding of the epistemology of science (relation between theory and experiment, insight to how scientific knowledge is created). Klopfer (1990) talks about the nature of scientific enquiry (discussed in last section).

5.6.1 Critique of the nature of science domain

An understanding of the empirical nature of science is given as a significant argument for labwork activities, both among researchers and teachers, e.g. (Swain et al. 1999; Leach 2002). On the other hand, problems are attached to teaching the nature of science through labwork activities. As Wellington states

> It is a tall order to expect science teachers, most of whom will have spent little or no time during their science degrees in considering the nature of science, to convey all these messages about science in busy laboratories - or to find the time and the strategies to teach these ideas explicitly.
>
> (Wellington (1998b), pp. 10-11)

As was also the case of the conceptual, skills and enquiry domains, the concept of the empirical nature of science domain has to be clarified and discussed in relation to school laboratories.

5.6.2 Understanding the nature of science domain

Wellington (1998b) states that one of the accusations against practical work in school science is that it has failed to reflect 'real science', to which he gives three counterarguments: How could it?, why should it? and what is ‘real science’? He elaborates by stating that such a thing as ‘real science’ does not exist as an unequivocal thing, in the same way as ‘the scientific method’ also does not exist. The phases of the discovery approach and the process approach fail, since they all are based on one understanding of the scientific approach. On the other hand, he states, this does not imply that practical work cannot teach students about the nature of science. Seven messages about science as an activity can be conveyed:

1. In science, experiments are not conducted which are independent of theory; that is, experiments are not one in a theoretical vacuum.
2. As a result, predictions, observations and inferences are theory-laden.
3. Scientists normally work as members of communities, often in institutions - science is a social activity which involves people. These people have personal attitudes, views, opinions and prejudices.
4. Scientists work in a social, cultural, historical and political context. This context determines how far they are funded and pursued. Research pursued and methods used in Victorian England or Nazi Germany have not been, and will not be, acceptable in other eras.
5. Scientific theories do not follow logically from experimental data (the fallacy of induction). Experiments may be derived from or suggested by theories - but theories are not fully determined by or derived from experiments (things like human beings and ‘leap of the imagination’ are needed in the middle).
6. Unlike Premier League football managers, established theories are not dismissed just because of a few bad results. Similarly, the choice between competing theories is not made purely on empirical/experimental grounds. Theories are not confirmed or proven, but can be supported, by experimental results. Theories can be shown to be false (falsified) by experimental data.
7. Science has methods but does not have *one method*. No scientific method follow a set, algorithmic procedure or a set of rules. Science also involved tacit, implicit, personal knowledge.

Three points are linked to this: First, students need to be taught or shown how to observe things, this does not come by itself. Second, teachers cannot teach theory through practical work; students will not induce, deduce or discover the theory by experiencing phenomena or events or observations. Phenomena experience can (maybe) teach knowledge *that* but not knowledge *why* (students can experience a metal bar expanding when heated, but not why this happens). Third, students need to be taught that a few anomalous results of the practical work do not lead to an abandonment of a theory. It takes a lot of judgement (prior theoretical knowledge) to decide which results are anomalous.

Leach (2002) points out that almost no matter which aim you pose for labwork, it draws upon understanding of the nature of science, exemplified through understanding the nature of empirical data, the nature of scientific knowledge claims, the way in which knowledge claims and data are related, the purposes of using techniques, procedures and instruments, etc.

He cites several studies showing how students' images of science constrain their performance in the student laboratory (Séré et al. 1993; Ryder and Leach 1999). When doing labwork, students have to make decisions. The decisions are of a different kind depending on which extent the labwork activities are designed as guided or more open-ended.

> In order to make these kinds of decisions during labwork, or understand the decisions made by those who designed the labwork tasks, students have to draw upon understandings of the nature of the data and knowledge claims that they are working with, and how they relate to each other.
>
> (Leach (2002), p. 42)

Leach (2002) explains his claims of the correlations between labwork activities and nature of science through a number of hypotheses about students' images of nature of science in relation to labwork activities, which should and could be sorted out through a more careful design of labwork activities.

Hypotheses about students' images of data and measurement

- Many students consider that, with good enough apparatus and enough care, it is possible to make a perfect measurement of a quantity. That is, they assume that measurement can be perfectly *accurate*. Others consider that any measurement is subject to some uncertainty, and so obtaining accurate values is problematic.
- Some students do not recognize the kinds of empirical evidence on which scientific knowledge claims are based. In the case of measured data, they think that it is only possible to judge the quality of a measurement from a knowledge of the 'true' value, given by an authority source. That is, they do not recognize that decisions about *precision* can be made from set of measurements. Other students think it is possible to judge the 'quality' of measured data from a set of repeated measurements. That is, they reason that data sets can be evaluated in their own terms to make decisions about accuracy and precision.
- Many students see data reduction and presentation as a process of *summarizing* data and see procedures like joining data points on a graph, drawing a 'best fit' straight lines, or drawing smooth curves as *routine heuristics* - that is, they see the process as independent of theory. They believe that there are standard techniques for arriving at a 'perfect' description of data. Others see such procedures as a process of proposing *tentative hypotheses about a relation between variables*. That is, they believe that experimenters (and computers) make decisions during data reduction and presentation according to existing models.

Hypotheses about students' images of the nature of investigation

- Some students think that the logic of proof and falsification is symmetrical: data that logically support a law 'prove' the law, in the same way that data that do not support a law logically falsify it.

- Some students think that most/all questions about natural phenomena are answerable by collection observational data and looking for correlations. Explanatory theories (models) 'emerge' from this data in a logical way: there is only one possible interpretation. Other students think that prior models (theories, hypotheses) influence decisions about what what to collect and how it is interpreted, and that observation and measurement are intended to test these models. Again, the testing is based on logic: only one interpretation is possible. Others think that a data base is first collected on the basis of embryonic theories and hypotheses - more robust models are then proposed as conjecture to account for existing, and anticipated data. Then predictions derived from these may be tested by planned observations or experiments, but more than one interpretation is possible due to the conjectural nature of theory.
- Many students see practical activities in the teaching lab as exercises to reproduce well-known results, or to illustrate important theories/models, no matter how the task is actually presented by the teacher. They do not recognise the labwork as an exercise in 'finding out'. Amongst these students, some assume that knowledge claims can be 'proved' or 'disproved' by a single planned intervention, whereas others assume that the process of investigation involves a sequence of interventions, which may be modified in the light of experience.

Hypotheses about students' images of the nature of theory

- Some students believe that scientific theories are really descriptions of natural phenomena: there is a one-to-one correspondence between theory and 'reality'. Such students believe that it is a straightforward empirical process to show that scientific theories are 'true'. Others believe that theories are mode-like, and do not simply describe reality. However, such students still believe that it is a straightforward empirical process to show that scientific theories are 'true'. Others believe that theories are model-like, and this means that it is NOT a straightforward process to show that a scientific theory is 'true'.

Hypotheses about students' images of the nature of explanation

- Some students do not recognise the different levels, types and purposes of explanation that are used in science (Examples: teleological, causal, descriptive, model-based). However, this work refers mainly to pre-adolescent students.

Hypotheses about students' images of the nature of public scientific knowledge

- Some students think that all the knowledge claims made by science are of the same status. They do not recognise the role of the scientific community in the validation of public knowledge. Others recognize that some knowledge claims are widely accepted within the scientific community, whereas others are still the subjects of investigation and debate.

5.6.3 My view

I was taught physics without much emphasis on the nature of science, epistemology, philosophy of ideas etc., and you can (to some extent) learn conceptual and procedural physics without it. But having later been reading about nature of science, a much more nuanced and fulfilling view on the field of physics emerges.

It is true how school labwork activities might cause quite distorted views on the nature of science, such as presented by Leach (2002), and being aware of these hypotheses can cause this to be discussed and refined. But the rhetoric and the task design have to be changed for some labwork activities aiming for understanding nature of science, where getting the right result - or explaining why the right result did not occur - should not be the aim of the labwork.

Teaching about the nature of science will provide the students with an understanding of how science works, and thereby taking away the 'voodoo' of science.

When discussing the conceptual domain and the gaining the feel of phenomena, Millar (1998, p. 26) expresses the importance of *producing* the phenomenon. Producing a phenomenon, he states, is a ritualized display of the power of the scientific knowledge involved, implicitly proclaiming its power by being able to predict or replicate an event, reliably and regularly, before the very eyes of the student. Science has such an immense understanding of the nature, that we are able to understand and predict its behaviour (at least to some extent).

To summarize the arguments by Wellington (1998b), Leach (2002) and Millar (1998) table 5.9 is developed.

Table 5.9 Summarized table of arguments for labwork activities in the nature of science domain.

Main purpose	*Description*
Predictability	Understanding that within the uncertainties physical phenomena are predictable and reproducible
Data and measurements	Understanding how perfect accuracy cannot be obtained. Understanding the role of random and systematic uncertainties.
Methods	Understanding how there are methods in science, but not *one* method (e.g. how data treatment are theory-dependent and not a standard procedure)
Investigations	Understanding the anti-symmetry of proof and falsification, the fallacy of induction, and the existence of several interpretations of same data
Theory	Understanding how theory is a simplified model of a more complex phenomenon
Explanation	Understanding the different levels, types and purposes of explanation used in physics
Public knowledge	Understanding that some knowledge claims are widely accepted within the scientific community, whereas others are still the subjects of investigation and debate. Also understanding that physics is developed by humans and exist in a social, cultural, historical and political context

5.7 Scientific attitudes domain

Shulman and Tamir (1973) talk about attitudes as e.g. curiosity, interest, risk-taking, objectivity, precision, confidence, perseverance, satisfaction, responsibility, consensus and collaboration, liking science. Newton (1979) talks about critical attitudes under the headline of scientific method and attitudes of perseverance under the affective headline. Hellingman (1982) talks about developing a sense of curiosity. Woolnough (1991c) talks about labwork for vocational reasons including attitudes students will find useful in later working life.

Boud et al. (1980) have on their list of objectives for teachers to rate, three entrances: to teach the principles and attitudes of doing experimental work in the subject, to foster 'critical awareness' (for example extraction of all information from data, avoiding systematic errors), and to provide a stimulant to independent thinking.

5.7.1 Critique of the scientific attitudes domain

Scientific attitudes can be understood as curiosity, risk-taking, objectivity, precision, perseverance, responsibility, consensus, critical awareness, open mindedness, honesty, willingness to suspend judgement, confidence, impartiality, openness, scepticism, intellectual honesty, a willingness to exercise caution when handling evidence, humility, anti-authoritarianism, collaboration, respect for empirical evidence, and a commitment to general beliefs such as belief in the understandability of nature and in the existence of natural cause-and-effect relationships. All of these attitudes are expected to be hold by scientists.

The idea about scientific attitudes played a crucial role in the 1970s and 1980s, where after it experienced a hard critique on two levels. Firstly, studies showed poor outcomes on the scientific attitudes account, and secondly, the idea about scientific attitudes, such as necessarily hold by scientists, began to be questioned.

For the first counter-argument of scientific attitudes:

> Most of these research studies have shown no significant differences between the instructional methods as measured by standard paper-and-pencil tests in student achievement, attitude, critical thinking, and in knowledge of the processes of science.
>
> (Hofstein and Lunetta (1982), p. 202)

And for the second counter-argument of the validity of scientific attitudes as hold by scientists, Hodson (1990) argues against using scientific attitudes as an argument for labwork activities. Scientific attitudes, defined as those approaches and attitudes towards information, ideas and procedures considered essential for practitioners of science, need to be discussed in relation to whether these are necessary for the successful practice of science, and whether they are actually trained in the practical work. Hodson (1990) states three questions, which should be bared in mind when teaching scientific attitudes: Is the practical work likely to promote these attitudes? Are the desirable? Do real scientists possess these characteristics? Hodson (1990) states that these questions most likely will be answered negatively.

5.7.2 Understanding the scientific attitudes domain

In the chapter by Gardner and Gauld in Hegarty-Hazel (1990b), scientific attitudes along with affective reasons are investigated. Scientific attitudes are describes as "…personality traits related to habitual styles of thinking (e.g. 'open-mindedness', 'honesty') which scientists are presumed to display." (Gardner and Gauld (1990), p. 132).

As a reply to the critique by Hodson (1990) concerning questioning if scientists even hold these attitudes, Gardner and Gauld (1990) state that there might be scientists who are closed-minded or dishonest, but these are likely to be regarded with disproval in the scientific community.

According to Gardner and Gauld (1990, p. 147) it has long been believed that if aiming for making students act in a scientific manner in and outside the school laboratory, it is not sufficient simply to teach knowledge about the various procedures, techniques and problem-solving skills which are thought to be central to scientistic activity. "Knowledge and skills must be accompanied by a willingness to put these into practice at the appropriate time and in the appropriate manner. It is this willingness that constitutes the scientific attitude." (Gardner and Gauld (1990), p. 147)

They further suggest how the special role of school labwork activities can provide a setting for developing scientific attitudes.

Quoting various studies investigating the effect of teaching scientific attitudes in labwork tasks show diverging results, primarily due to the poor study design. Especially interesting is the study by Fordham (1980), since it reports how students prefer to hand in reports of data supporting the theory, since they expect better grades for such results. This lead Gardner and Gauld (1990) to conclude "Merely being in the laboratory and doing labwork they do not, by themselves, foster scientific attitudes: it is the quality of the experiences that students have there that is crucial." (Gardner and Gauld (1990), p. 150)

They conclude how a constructivist approach to labwork activities is most likely a way to teach scientific attitudes, and here they place emphasis on teachers' investigations of students' prior beliefs.

> Relevant experiences are those which directly engage and challenge students' prior conceptual frameworks, not in an attempt to demonstrate them to be silly or wrong, but for the purposes of showing how, in the scientific community, ideas (one's own and other people's) and new experiences interact.
>
> (Gardner and Gauld (1990), p. 150)

5.7.3 My view

I find relevance in Fordham (1980)'s point of making sure students do not perceive data fitting the theory to be 'better' than alternative data. This concurs with the observations I did in the PE labwork during my pilots. On the other hand, I find Hodson (1990)'s critique most relevant. Attitudes are to a high extent personal. Also, I am not sure the image of a scientist fulfilling all of the above mentioned scientific attitudes is completely truthful.

But what is missing from the discussion of scientific attitudes in relation to labwork activities is learning to approach a problem, where the solution is not already given. Labwork activities might provide students with the feeling they are able to approach a scientific problem in an empirical way and actually solving it. To gain this attitude is not only relevant in the physics classroom, but is an ability, which is valuable in most of the issues of life. These ideas are touched upon in section 5.5, especially in the quote at page 173.

This attitude towards problems as being a potential hurdle which hold a solution on the other side (that the student is able to find), is related to the idea of general education, and is of a general kind. And here labwork activities have a strong role to play.

5.8 Affective domain

The affective domain is understood as feelings of the discipline, such as the students' interest in physics, their enjoyment and satisfaction of working with physics, etc.

When discussing the aims for labwork activities, Shulman and Tamir (1973) talk about attitudes, including among other things affective reasons, such as curiosity, interest, satisfaction, collaboration, and liking science. Newton (1979) emphasizes affective aims, which he explains as interest, enjoyment, attitudes of perseverance, open-mindedness, critical mindedness, objectivity, and intellectual honesty. Hellingman (1982) talks about labwork activities as a way to develop enjoyment of scientific learning experiences and developing a sense of curiosity. Hegarty-Hazel (1990c) discuss how labwork activities might foster a sense of success, motivate, and gain control in science. Tamir (1991) talks about how practical experiences are enjoyed by the students, and are getting them motivated and interested in science. Woolnough (1991c) underlines the importance of affective factors. Wellington (1994a) states how labwork activities can be used to motivate/stimulate, understood as a way to entertain, arouse curiosity, enhance attitudes, develop interest, and fascinate. Højgaard Jensen (2002) talks about how labwork is a motivational way of approaching theoretical concepts. Goldbech and Paulsen (2004) emphasize labwork activities as a way to gain interest and motivation, and to develop social skills and attitudes due to group work.

Kerr (1963) in his list of aims for labwork activities used as a questionnaire for teachers, has one aim of labwork activities as a way to arouse and maintain interest in the subject. In the same way Boud et al. (1980) talk about labwork activities as a way to instil confidence in the subject, and to stimulate and maintain students' interest in the subject.

5.8.1 Critique of the affective domain

To which extent affective arguments are reasonable arguments for school labwork activities are discussed by a number of authors.

According to Wellington (2005) the affective domain has been disregarded for a number of years, but now it is beginning to be viewed as significant. Various studies have investigated the motivational effect of labwork activities, and though the results are vague, most favour for labwork activities as motivating (Hofstein 1988; Myers and Fouts 1992). Gott and Duggan (1996) underlines how labwork activities enhance personal growth, and Ford (1999) describes how the social interaction during labwork acts as a catalyst for learning. Olsen et al. (1996) describes how the students' autonomy enhances when engaging in (open-ended) labwork activities. Woolnough (1991a) indicates the importance of the affective and social factors, when explaining how a student might fail, not because he cannot, but because he does not want to.

Other authors (Head 1982; Hodson 1990; Wellington 2005) report diverging results, which are influenced by school level, gender, and school abilities. Hodson (1990) argues that motivation is personal, and curiosity changes with different ages, and Woolnough and Allsop (1985) refer studies showing that for many students, most often girls, practical work hold no interest at all.

According to Woolnough and Allsop (1985) students most often prefer practical work over theory work, but this may say more about the other methods of teaching than the affective benefits of practical work.

5.8.2 Understanding the affective domain

Gardner and Gauld (1990) have in the book edited by Hegarty-Hazel written an entire chapter about the affective and attitude domains. The part about the affective domain - which they call attitudes to science - describes it as "...students' favourable or unfavourable reactions to some specific attitude object (e.g. 'learning physics', 'doing chemistry labwork'. This construct includes terms such as *interest, enjoyment* and *satisfaction.*" (Gardner and Gauld (1990), p. 132, original emphasis)

In relation to attitudes to science, Gardner and Gauld (1990) refer surveys showing how teachers and students emphasize different aims of labwork activities as most important. Teachers tend to enhance the cognitive arguments for labwork activities, whereas students to a higher extent emphasize affective and psychomotor arguments.

The level of interest in labwork activities activities are influenced by a number of things, such as the facilities, the time allotted, the fact that labwork activities are a variety from other teaching modes, the level of cognitive challenge (too easy or too difficult will make the affective level decrease), to which extent the labwork is related to known theory, the teacher's organizational ability, the autonomy embedded in the labwork, the level of individualization of the students, and the level of social interaction during the labwork.

As was also the case of the case teachers, Gardner and Gauld (1990) emphasize how students and teachers perceive labwork activities positively due to variety from other modes of teaching. Students' interests in labwork activities are also highly related to the cognitive challenge of the labwork. Cookbook or routine labwork activities, they state, are hardly likely to enhance student interest. On the other hand, labwork activities so difficult they cannot be understood or carried out are also hardly likely to generate interest either.

5.8.3 My view

As for the case of the conceptual domain, studies show varying results in the trial of correlating labwork activities to affective arguments, and for good reasons. Whether a student is enjoying a labwork might be influenced both by factors related to labwork activities and not related to labwork activities, and it is not reasonable to expect a clear-cut answer.

On the other hand, everybody agrees that a teacher should try to enhance the students' affective feelings towards whatever the students engage in - but that is not related specifically to labwork activities.

5.9 Summery and reflections

After this review of the various authors playing on the research scene of the role and purpose of practical work and my views and adds to this, some reflections on the way the arguments for labwork activities is presented in literature are in place.

But before this the learning goals of labwork activities described in the curriculum and learning plans for the 2003/2005 reform are investigated in relation to the developed scheme of six generel purposes of labwork tasks. The results are seen in table 5.10.

As seen, the list of learning goals for labwork activities are 'categorizable' within the six general purposes of labwork tasks, such as developed here, indicating again the six-fold purpose scheme covers all purposes (besides the pure pragmatic, such as exam relevance, teaching differentiation, teaching varying, etc.). Still one should notice how this table indicate how labwork activities should cover a lot of learning goals in fairly short time, and thereby risking to fall into the pitfall of expecting one labwork to be able to fulfil all labwork goals, and thereby making it impossible to focus on one or a few goals.

5.9.1 Missing discussions in the literature

When reading through and thinking about the existing literature and the curriculum I find some discussions missing or not fully discussed, which I will try to outline here.

Firstly is the discussion of the *degree of detail*, as discussed in section 5.3. One could easily set up a list of purposes of labwork activities miles long, including aims of the type of learning how to include data points on an exponential graph in Excel, to read off a thermometer and to be acquainted with the attraction and compulsion of two magnets. Or one could set up a list of aims for labwork activities stating how students should be able to link the world of theories and models with the world of phenomena. And in between that are a number of categorization possibilities. So when is the amount of categories enough to actually state something and low enough to still be able to hold them in your head? I have in the previous tried to reach a categorization level that to my extent fulfils this.

Secondly is the interpretation of *means and goals*. Should physics labwork activities serve to learn to do physics labwork activities, should they serve the learning of physics, should they serve the learning in other disciplines (e.g. mathematics), or should labwork activities serve to make the students more capable to act in the world around them? Labwork activities might serve each of these, but this puts a very different perspective on the activity.

Thirdly, when discussing labwork activities, most literature discuss *science, as opposed to the different science disciplines*. There are some large potential pitfalls to this. The nature of the various science disciplines are quite different, since e.g. physics is mostly about understanding an idealization of the world, and e.g. biology is much more about describing it. Chemistry might place much more emphasis on the technical skills compared to physics, since in chemistry both the techniques are less divergent and the aim of chemistry is to a higher extent than in physics to investigate special cases for the case itself. Therefore it is not surprising that Kerr (1963) finds different results for teachers teaching different school disciplines, simply because the nature of the disciplines is different. And that ought to be displayed in the literature.

Thirdly, the *school levels* are placed side by side in the discussion. Few discuss, e.g. Hegarty-Hazel (1990b) that the 'general education'-related arguments are of a greater significance in the early school years, whereas the vocational arguments become more and more significant up through the school levels. Besides the obvious argument of specialization, also this might be displayed through the students' abilities in mathematics. In elementary school the students have a lower mathematical knowledge base, and therefore the primary way of engaging actively in physics is through labwork activities (though maybe fairly qualitative). As their mathematical knowledge base increases, the need of labwork activities for engaging in scientific enquiry decreases, since now physics can be investigated through simulations, models, etc. Finally at university level, labwork activities are almost lacking as a teaching method, and are - if at all - used to show the students some historically important experiments.

Fourthly, much literature does not discuss the *differences of practical work*. Practical work has different nature; deductive versus inductive, teacher-directed versus student-directed, measure-driven versus concept-driven, open-ended versus closed-ended, and so on. These discussions I find lacking in the existing literature (not including Gott and Duggan (1995), Woolnough and Allsop (1985), etc.).

Finally, the understanding of labwork aims might have the same name, but have a *different taxonomy level*. In most of the referred literature the normal procedure is to describe previous understandings of purposes of practical work (e.g. as extracted from curricula or teachers), give a hard critique of these, and set up some new, which often could be equalled the previous ones, just with a different taxonomy level.

So now I leave the discussion of labwork aims, and pick it up in the next chapter (chapter 6), where the six identified labwork aims are linked to different labwork types as well as to the most commonly used labwork activities in the Danish Gymnasium physics.

Table 5.10 Purposes and possible goals for practical work in the Gymnasium school physics, based on a read-through of the regulation of 2003/2005 physics curriculum.

Goal	*Sub-goal*	*Level*
Conceptual	Illustrate a theory	C
	Verify a theory	C
	Support a theory	A
	Gain experience with concepts and laws	C
	Introduce new subjects	CBA
	Tool to work with concepts and connections	CBA
	Gain theoretical based scientific insight	C
	Gain experience with scientific problems and their handling	C
	Set a ground for modeling	C
	First experience with physical phenomena	CBA
	Produce data for further data analysis	A
Procedural	Gain decent customs in the lab	CA
	Know and use commonly found equipment	CA
	Know about security in the lab	CBA
	Estimate moments of risk	CBA
	Plan a labwork with given problem and equipment	BA
	Identify relevant variables	A
	Perform variable control	A
	Perform a labwork	CBA
	Make systematic observations	A
	Perform experiments systematic and as planned	A
	Describe a labwork	CBA
	Keep a lab journal	CBA
	Present data reasonable	CBA
	Analyze data	CBA
	Manage (large) data sets	CBA
	Estimate the sources of error	CBA
	Estimate the uncertainty in measurements and results	CBA
	Describe connections between experimental data	A
	Use theory to explain results	CBA
	Perform systematic testing of hypotheses	CBA
	Gain ability to generalize	C
	Gain ability to disregard	C
Inquiry	Plan a labwork with an open problem and equipment	A
	Make hypotheses	CBA
	Understand that labwork can strengthen, modify or reject hypotheses and models	CBA
Affective	Gain motivation by wonder	CBA
	Gain interest	CBA
	Gain engagement	CBA
Nature of Science	Comfort with the experimental grounds of science	CBA
	The research discipline of physics is manmade	CBA
	The research discipline of physics is idealized	CBA
	Be able to put labwork activities into a larger perspective	CBA
	Understand diff. between qualitative and quantitative labs	CBA
Scientific attitudes	Perform scientific observations	CBA
	Be creative	CBA
	Be independent	CBA
	Be curious	CBA
	Perform reasoning	CBA
	Be innovate	CBA
Pragmatic	Gain skills of cooperation	CBA
	Can include differentiation in the teaching	CBA
	Give students an equal basis	CBA
	Exam relevance	BA

6 Linking labwork activities and purposes

In this chapter the models/tools of linking labwork activities to their purposes are developed.

Firstly, literature linking labwork types and general labwork purposes are reviewed (in section 6.1). Here different types of labwork activities are related to the different types of general labwork purposes (such as these are described and discussed in the previous chapter).

Based on the literature review a further developed tool for linking labwork types to the found general labwork purposes is developed in section 6.2.

This is then followed by an investigation of the labwork activities commonly found in the Danish Gymnasium physics classes, see section 6.3. Here is drawn upon both the core content description found in the curriculum, and more importantly on the collected labguides and lab reports from various sources. From this a typical series of labwork activities is developed. Each labwork is classified according to the categorization scheme of labwork types developed in the previous section. Using the tool for linking labwork types and labwork purposes, it is clear what general purposes these specific labwork tasks (can) serve.

As previously discussed, for specific labwork activities it is important to justify them according to quite specific purposes. Therefore a further tool is developed in order to explain the specific purposes for specific tasks (see section 6.4). This is visualized by a matrix, with one axes is the exemplary series of practical works, and the other axes having the list of sub-purposes relevant for these types of labwork activities. The matrix is filled out and discussed, giving an overview of which practical works is serving which specific purposes.

Finally, in section 6.5 reflections about these developed tools, their justification and their validity are given.

6.1 Earlier work on linking labwork activities and purposes

As part of the discussion of how a specific labwork is not likely to serve all purposes existing for labwork activities, research literature discusses how different types of labwork activities can serve different types of purposes. Here these research reflections are reviewed.

Various literature categorizes labwork types either as describing the ongoing practise or as a normative bid on a better practise.

E.g. it has throughout history been discussed if labwork activities should be inductive or deductive (see section 5.1.1). Millar et al. (1999, p. 35) talk about the obvious distinction between teacher demonstrations and students' practical work. Millar (1998, p. 25) talks about pedagogic and epistemic events in the laboratory, where the pedagogic events are to help learners to perceive the world in certain ways already known to the teacher and to the expert community of which he or she is a representative. The function of epistemic events is on the other hand to discover something new about the world.

Newton (1979) discusses open and closed experiments (less and more guided), where closed experiments seems to serve the didactic aim (clarify, order and extend experiences of natural phenomena, illustrating laws) and skill related aims (use of apparatus, specific manipulative skills, standard techniques, comprehension and execution of instructions, communication of results and conclusions), whereas open experiments serve other aims, such as learning about the scientific method (described as creative and logical reasoning, disciplined approach, critical attitudes) and affective aims (interest, enjoyment, attitudes of perseverance, open-mindedness, critical mindedness, objectivity, intellectual honesty).

Herron (1971) makes a further distinction between open and closed tasks, when talking about different levels of enquiry (confirmation/verification, structured, guided, and open) to describing whether the problem, procedure and conclusion are open or given, see table 6.1.

Table 6.1 Herron's description of different levels of enquiry.

Level	*Name*	*Problems*	*Ways*	*Answers*
0	Confirmation/verification	Given	Given	Given
1	Structured	Given	Given	Open
2	Guided	Given	Open	Open
3	Open	Open	Open	Open

Staer et al. (1998) report how 84 percent of the labwork activities used in high schools in Western Australia are in level 0 or 1. Inspired by Herron's ideas about task categorizations, Christiansen et al. (2010) develop a 2 times 2 matrix of science education problem types, talking about closed -, vague -, design -, and open problems, spanning the field of problem formulation- and problem solution space, see table 6.2.

Table 6.2 Distinction between problem types in science education, as developed by Christiansen et al. (2010).

		Problem formulation	
		Closed	*Open*
Problem solution	*Closed*	Closed problems	Vague problems
	Open	Design problems	Open problems

Hodson (1990, p. 39) talks about four types of labwork activities: *development of manipulative skills*, *the measurement of 'physical constants'*, *illustrations of a key concept*, and *inquiries* that enable children to conduct their own investigations.

Kirschner and Meester (1988, pp. 89-91) also operate with a fourfold classification of types of labwork activities: *Academic or formal labwork activities* (traditional, structured, convergent, cookbook) designed to verify laws, principles, concepts and facts previously taught. *Experimental labwork* (open-ended, inductive, discovery oriented, unstructured) designed to challenge understanding and creativity. *Divergent labwork* (taking off from common start, but else wise open-ended) designed to challenge understanding and creativity with a higher degree of instructional organization. And *experimentation labwork activities* (data analysis, experimental graph plotting, curve fitting, accuracy, precision, significant digits, estimation and propagation of uncertainties, difference between random and systematic errors, etc.) designed to develop procedural skills.

Gott et al. (1988) attempt to describe in broad categories the types of labwork activities existing, and develop five distinct types: *Skill* aiming for acquiring a particular skill, *observations* providing opportunities for pupils to use their conceptual framework in relating real objects and events to scientific ideas, *enquiries* aiming for discovering or acquiring a concept, law or principle, *illustrations* 'proving' or verifying a particular concept, law or principle, and *investigations* providing opportunities for pupils to use concepts, cognitive processes and skills to solve a problem. Others use 'enquiry' and 'investigations' interchangeably, but here they distinguish by understanding enquiry as carefully structured tasks allowing pupils to discover a particular concept for themselves, whereas investigations offer several alternative ways of reaching a solution to the problem, and are in nature much more unstructured and less controlled.

Making use of the five-fold categorization of labwork activities developed by Gott et al. (1988) (see page 189), Gott and Duggan (1995) link these labwork types with labwork aims, falling into categories of conceptual and procedural understanding. This makes them able to see which emphasis the different teaching methods principally put on either conceptual or procedural understanding, along with what kind of understanding - as given of the taxonomies - the practical works aim for, see table 6.3.

Table 6.3 Gott and Duggan's link between labwork types and labwork aims (conceptual and procedural).

Type	*Aim*	*Conceptual*	*Procedural*
Skills	To acquire a particular skill		Acquisition
Observation	To provide opportunities for pupils to use their conceptual framework in relating real objects and events to scientific ideas	Application	
Enquiry	To discover or acquire a concept, law or principle	Acquisition	
Illustration	To 'prove' or verify a particular concept, law or principle	Consolidation	
Investigation	To provide opportunities for pupils to use concepts, cognitive processes and skills to solve a problem	Application	Application / synthesis

Woolnough and Allsop (1985) operate with three types of labwork activities and their related aims: *exercises* designed to develop practical skills and techniques, *investigations* designed to let the students be problem-solving scientists, and *experiences* designed to let the students get a feel for phenomena.

Further they discuss the possibility of aiming for more than one purpose of a practical work, which they do not dismiss, but give the concern:

> In the past great disservice has been done to practical work in trying to use it to teach scientific process and scientific concepts simultaneously. [...] What is import, however, in teaching is that we should all the time have before us the question 'What is the prime aim?' In other words, what am I trying to do in this experiment? To teach skill and techniques? To give experience of working like a problem-solving scientist? Or to get 'a feel' for phenomena? We need to be careful to ensure that in trying to satisfy more than one aim at a time we do not frustrate the achievement of any one of them.
>
> (Woolnough and Allsop (1985), p. 60)

And the students need to be aware of this prime aim:

> The student needs to be as aware of the aims of the practical as the teacher is. The student needs to be clear not only about the specific objective of a practical, but also about the over-riding aim, for that will need to be stated so that the student may know how to approach the task. If our aim is to develop the scientific skill of accurate measurement, this will require precision of quite different order from that of a practical aimed at getting a feel for a phenomenon, or one used as a quick test experiment as part of an investigation.
>
> (Woolnough and Allsop (1985), p. 60)

Later, Woolnough (1989) explains how it might be needed to go through the cycle of play (getting a feel for phenomena through *experiences*), practice in the area of competence (learning skills and processes in *exercises*) and exploring the frontier area (being a problem solving scientist through *investigations*). The importance is the continual oscillation between these three areas, where the skills and processes are given a role through:

> . . . it receives its *raison d'etre* only as part of doing investigational science. It must be seen alongside the other vital attributes needed in making a good scientist, the affective aspects of commitment and confidence, the personal insights which come both through formal and informal learning, and the tacit knowledge that comes through experience, both structured and in play. These four aspects must continually be interacted, in a flexible and individualistic way, throughout the scientific education of the students.
>
> (Woolnough (1989), p. 131)

Millar et al. (1999) and Millar et al. (2002) analyse the various kinds of practical work, since, as they state:

> Practical work in science [. . .] is very varied in type, and in intension. If we, as teachers and researchers, want to explore the effectiveness of practical work in achieving educational goals, then we need to be clear about the different types of practical work which are (or could be) undertaken in classes, and their different purposes and characteristics. In this paper, a typology (a 'map') is presented, and some of its implications for teaching and research are explored. A 'map' of this sort may help us see how to address the key question of the effectiveness of practical work.
>
> (Millar et al. (1999), p. 33)

Initially they state that since the subject matter of science is the natural world around us, including what is contains and how it works, then it is natural to teach science also by giving the students the opportunity to act with the materials themselves instead of only telling or showing representations (like photos, videos and diagrams).

Then they add up a number of things, practical work offers the students: helps teachers to communicate information and ideas about the natural world, helps students develop understanding of the scientific approach to enquiry, and gives students opportunities for enjoyment, which fall in the categories of conceptual domain, enquiry domain and affective domain.

They state "In our view, the core purpose of practical activity in science teaching is to help the student make links between the domain of objects and observable things, and the domain of ideas." (Millar et al. (1999), p. 35)

Their classification system of different kinds of practical works then takes the base of focusing on the kind of physical actions and operations required of the student in dealing with objects and observables on the one hand, and the kinds of mental actions and operations required of the student in dealing with ideas on the other.

Their developed map of practical work contains two major dimensions; namely the intended learning outcome (or learning objective) of the task, and the task design itself.

It has been tried to sum up their map in a matrix, which can be found in table 6.4.

Table 6.4 The main dimensions of a map of practical work tasks, and their sub-dimensions. The A dimension is the learning objectives or intended learning outcomes, and the B dimension is the task design. This is extracted from Millar et al. (1999), p. 40.

		A: Learning objectives	
		Content	Process
B1	Design features		
B2	Practical context		
B3	Student's record of work		

This matrix does not explain a lot. Initially it is important to notice how they divide the intended learning outcomes into two categories of content and process, meaning they see the objectives of practical work to fall into content and/or process. Second, their overall understanding of the different kinds of practical work is categorized within what they call the task design, subdivided into design features, practical context and student's record of work on the task. What they mean by the categories of the two dimensions can be seen in the following two tables 6.5 and 6.6.

Table 6.5 gives a description of the intended learning outcomes of practical work. This is divided into categories of content and processes, and each of these again has subcategories. The authors themselves clarify briefly what they mean by the terms of fact and relationship (fact being a readily agreed statement like the boiling temperature of water, and relationship being a pattern or regularity in the behaviour of a set of objects or substances, or an empirical law).

It is outlined how most practical work will have the goal of reaching more than one of the subcategories of intended learning outcomes.

The article then follows up on giving further descriptions of each of the subcategories, following up with 13(!) tables, which each piece of practical work can be categorized within. In the end they discuss the use of all these schemes and tables. They see two major uses. First their map can be used to compare different kinds of practical work, to see where they are similar, and where they differ. This can then add up to an understanding of which kind of practical works are under- and overused in the science classes. The second use is to make a more clear way of posing the question of the effectiveness of practical work, since this map has shown the numerical kinds of practical work, which can be done and is done in the science classes. By further research using this map,

Table 6.5 Description of the dimension of learning objective (intended learning outcomes) (A)

Content	
A.a	To help students identify objects and phenomena and become familiar with them
A.b	To help students learn a fact (or facts)
A.c	To help students learn a concept
A.d	To help students learn a relationship
A.e	To help students learn a theory/model
Process	
A.f	To help students learn how to use a standard laboratory instrument, or to set up and use a standard piece of apparatus
A.g	To help students learn how to carry out a standard procedure
A.h	To help students learn how to plan an investigation to address a specific question or problem
A.i	To help students learn how to process data
A.j	To help students learn how to use data to support a conclusion
A.k	To help students learn how to communicate the results of their work

Table 6.6 Description of the task design dimension (B)

B1	**Design features of the task**	
	B1.1	What students are intended to do with objects and observables
	B1.2	What students are intended to do with ideas
	B1.3	Whether the task is objects- or ideas-driven
	B1.4	The degree of openness/closure of the task
	B1.5	The nature of student involvement in the task
B2	**Practical context of the task**	
	B2.1	The duration of the task
	B2.2	The people with whom the student interacts whilst carrying out the task
	B2.3	Information given to the student on the task
	B2.4	The type of apparatus involved
B3	**Student's record of work on the task**	
	B3.1	Nature of record
	B3.2	Purpose of record
	B3.3	Audience for record

they state, it should be possible to realize which kind of practical work that effectively reaches the intended learning outcomes:

> To make labwork more effective, then, we need to think harder about its use. Labwork includes a wide variety of tasks, designed to promote quite different kinds of learning. It does not make sense, therefore, to ask about the effectiveness of labwork in general. Instead we need to ask about the effectiveness of *specific* labwork tasks for achieving *specific* learning objectives. To do this systematically, one needs to be able to produce a *profile* of any labwork task. This would identify the learning objectives of the task and provide a detailed description of its key features.
>
> (Millar et al. (2002), p. 10, original emphasis)

6.1.1 Summary

For the case of the articles by Millar et al. (1999 2002), their idea about mapping the domain of varieties of practical work is very appealing to me. But when they write up their scheme I was somewhat disappointed, both by their description of the labwork purposes and by the labwork types. The main purpose of practical work is defined as either teaching content or process to the students, somehow leaving behind their own main argument of building bridges between the observable world and the world of scientific ideas/concepts. Their subdivisions of the labwork aims do not make the problems less profound. Their development of dimensions of the task design I do not find beneficial; I can see there lies some work in filling out these dimensions, but I do not see how that will provide a closer link between the design and the intended learning outcomes. Since no work on 'filling out the matrix' is done, I find this as an appealing idea which never leave the drawing board. And I do not really believe in their stated uses of their map, such as an understanding of which labwork activities are over- and under-used (as if only a homogeneous spread on each category will provide a reasonable teaching of labwork activities), and a potential quantitative measure of the labwork efficiency. But as described, I find their initial idea great, and I intend to take off from the same idea, but to develop (hopefully) a more useful and reflected scheme.

To do this, great use has been found in the linking made by Woolnough and Allsop (1985), Hodson (1990), Kirschner and Meester (1988) and Gott and Duggan (1995) linking their labwork purposes to types of labwork activities. In the following, these linking schemes are further developed in order to implement all six normative purposes of labwork tasks, as developed in the previous chapter.

6.2 Linking labwork types and labwork purposes

As the purposes of labwork have thoroughly been investigated in the previous chapter 5 and summed in six purposes (conceptual domain, procedural domain, enquiry domain, nature of science domain, scientific attitudes domain, and affective domain) now these labwork purposes should be linked to related labwork types.

Some studies in relating labwork purposes and labwork types exist and have been reviewed in the previous section (section 6.1). Based on this, six labwork types are recognized/developed having each of the six purposes as their main argument. These six labwork types are: *experiences* (conceptual domain), *exercises* (procedural skills domain), *investigations* (enquiry domain), *meta-tasks* (nature of science domain), *vague problems* (scientific attitudes domain), and *Christmas experiments* (affective domain).

It is important to notice how this should be understood. It is not claimed that e.g. an exercise cannot serve any of the other purposes besides from the domain of procedural skills. But rather the other way around, if a teacher aims for teaching the students about the domain of procedural skills, then an exercise is the obvious and most direct choice.

In the following these six labwork types are further investigated. Labwork activities using the same equipment and investigating the same phenomenon can fall into either of the categories of labwork types; it is all depending on the way the task is intended, designed and presented. This point can be shown by exemplifying each of the labwork types for the topic of air resistance investigated through paper cake tins in table 6.7.

In the following six subsections, each labwork type is explained and the link to it potential learning outcomes is discussed. This work is a further development of the results from Woolnough and Allsop (1985) and Gott and Duggan (1995) discussed in section 6.1.

6.2.1 Experiences

Woolnough and Allsop (1985) talk about *experiences* aiming for giving the students a feel for the phenomenon. They are most likely short exploratory experiments, therefore often teachers are underrating their importance. These experiences should be detached from data handling, modelling, mathematics and statistics; emphasizing hands on. Many experiments tend to hide the phenomenon behind the complicated apparatus and processes. These experiences are not to collect data for further data handling, but merely to sense (see, feel, smell, hear, taste) the phenomenon for further discussions. Examples of experiences are pulling a rubber band, watching Brownian movement in smoke cells, seeing formation of oil films on water, feeling the pressure in compressing air in a syringe and moving arms in and out on a revolving stool.

This type of labwork obviously can be argued for in the conceptual domain, but following the ideas of Millar (1998), experiences also potentially serve the nature of science arguments, since producing (possible complex) phenomena serve the argument of reproducibility; and thereby evoking an understanding of the predictability of physical phenomena, which is so special to physics.

Table 6.7 Example of a physical phenomenon (air resistance on paper cake tins) investigated through each of the six labwork types.

Lab type	*Labwork example*
Experience	Predict-observe-explain labwork concerning falling cake paper tins (stacked or un-stacked), to see that the fall velocity increases with increased weight for a constant cross-section
Exercise	'Find an expression for air resistance on a paper cake tin in a free fall, and determine the coefficient of air resistance' (with a description of how to operate the equipment, which data to collect, and how to handle the data)
Investigation	'Investigate the air resistance of falling cake paper tins'
Meta-task	'How fast does a cake paper tin fall? How precise can this question be answered by use of this specific method, and what can be done to increase the precision?' 'By use of this specific experiment using falling paper cake tins, can we prove or disprove the v^2-law of air resistance?'
Vague problem	'How much heavier must a large cake paper tin be compared to a small cake paper tin for them to fall equally fast?'
Christmas experiment	Making a competition, where each student choose a paper cake tin among a number of various shapes, paper types, colours, sizes, masses etc. and letting them all drop their cake tins from the same height to see which lands first.

6.2.2 Exercises

Exercises, such as explained by Woolnough and Allsop (1985) or closed problems, such as given by Christiansen et al. (2010) are another way of doing labwork activities. Woolnough and Allsop (1985) define this type of labwork as a way to develop procedural skills, where it is clear to all parties how the process is more important that the content. Examples of exercises are: measurement of commonplace and personal dimensions (length, area, volume, weight), and estimation of dimensions and other measures such as room size and volume or weight or air in a room. As Woolnough and Allsop state, when engaging in exercises: "Many have gained enjoyment and a sense of wonder, as well as a deeper understanding of the order and patterns of the world, simply by learning to observe carefully the world around them." (Woolnough and Allsop (1985), p. 48) The authors especially argue against too complex apparatus, which will cause the skills-related aims of the exercise to drown in the confusions.

For the sake of developing practical skills and techniques, according to Woolnough and Allsop (1985), research have shown how students do not pick up these skills in a content-dominated practical work (where the students are only concerned about reaching the right answer, and therefore not place emphasis on their own observations).

But as is the tradition, exercises are often including unfamiliar and complex apparatus and physical phenomena along with clear-cut instructional labguides; exercises are not always following the ideal form described by Woolnough and Allsop (1985).

6.2.3 Investigations

Investigations, such as defined by Woolnough and Allsop (1985), are designed to give students practice (and consequently the opportunity to develop competence) in working like a real problem-solving scientist. These are open-ended and openly-formulated problems.

Investigations can take many different forms: half an hour to one half a term, but most often of a few weeks of work; individually or in groups; in class or at home; related to the scientific content (leading into or derived from it) or independent of the ongoing scientific content. But all going through the chain of problem-solving (PRIME) (see page 168). Woolnough and Allsop, p. 53 believe these investigations will lead to a number of scientific attitudes and personal skills, like: satisfaction, commitment to the problem, leading to determined involvement, encourage and develop talents of originality, creativity, independence, self-fulfilment, self-confidence, and perseverance.

Examples of investigations are: How efficient as an energy converter is a bow and arrow, an electric motor or a plant? Investigate the way the shape of a card affects its strength, etc. Investigations are of the form, where the teacher does not know the answer in advance.

Obviously, investigations serve the main purpose of learning about the enquiry domain. While doing an investigation, the students need to draw upon a number of other domains (conceptual, procedural skills, scientific attitudes, etc.), but if either of these were the main purpose, then a less complex labwork type is preferred.

6.2.4 Meta-tasks

Meta-tasks are labwork activities designed to develop students' views on nature of science, such as these are described by Leach (2002) and Millar (1998).

Meta-tasks include tasks revealing the social and contextual nature of physics, by e.g. repeating historical experiments with identical equipment, or by doing labwork activities at research facilities. But meta-tasks are also labwork activities designed to investigate other sides to the nature of science, such as labwork activities designed to favour one model between several competing models and thereby teaching students about the development of physics and the philosophy of physics, or it could be a labwork designed to find a value of a physical constant including a discussion of the possibility of reaching the perfect accurate answer.

6.2.5 Vague problems

A number of arguments run against full-scale investigations, as these are critiqued as being used as having an inductive philosophy, being theory independent and causing dislike among the students. To distinguish between investigations, where the task is to go through the entire PRIME process including setting up the question or hypothesis to be investigated and tasks where the question or hypothesis are given, Christiansen et al. (2010) operate with a subcategory of investigations which they call vague problems, or openly-formulated closed-ended problems. Here the question or hypothesis are formulated by the teacher in an everyday language, and should from this be reformulated in 'physics language', investigated through an open process, and leading on to a by the teacher already known answer.

By such, the type of vague problems is identical to the investigations previously named, but now the hypotheses are formulated, and not left for the students to pose.

This type of labwork activities serves to give the students scientific attitudes, especially those of feeling confident in their own ability to 'figure it out'. As was also the case of investigations, a number of other purpose domains come into play while solving a vague problem, but if these are put forward as the main purpose of the labwork, this could be gained with more direct labwork types.

6.2.6 Christmas experiments

Finally are *Christmas experiments*. These labwork activities are included due to the following anecdote by physics education researcher Eric Mazur[1] concerning his teaching at the first year university course on classical mechanics. Here he often showed his students a number of demonstration experiments, where one of his favourites was to fire a powder extinguisher while he sat on a cart, thereby demonstrating the phenomenon of conservation of momentum. But upon questioning, his students were not able to account for and relate the physical phenomenon of conservation of momentum to the demonstration. It all drowned in the blast and mess of the power extinguisher. Mazur realized then how the demonstration did not serve the purpose of 'getting to know the phenomenon'.

[1] One of the persons behind the peer instruction ideas (Crouch and Mazur 2001)

Still, I claim, these types of labwork activities serve a purpose. Mazur most likely looked as he was having a great time during this demonstration. There are a lot of positive gains from showing how physics is fun, beautiful, operating with massive powers, etc., and therefore labwork activities should also sometimes just be explosions, and display of beautiful colours and fun, but these type of Christmas experiments will most likely drown other potential learning outcomes in the chaos, flashes and blasts.

6.2.7 Summary of linking labwork purposes and labwork types

To summarize the links between labwork types and labwork purposes, as discussed in the previous, a matrix is developed, see table 6.8.

Table 6.8 Linking labwork purposes and labwork types. The capital 'X' is to be understood as the main purpose of the task, and the '(X)' is to be understood as a potential - but not main - purpose of the task.

		Lab types					
		Experiences	*Exercises*	*Investigations*	*Meta-tasks*	*Vague problems*	*Christmas exp.*
Lab purposes	*Conceptual*	X	(X)	(X)	(X)	(X)	
	Procedural skills		X	(X)	(X)	(X)	
	Enquiry			X			
	Nature of Science	(X)		(X)	X		
	Scientific attitudes			(X)		X	
	Affective	(X)	(X)	(X)	(X)	(X)	X

As seen at the table, each labwork type has a specific labwork purpose - indicated with capital 'X'. If one seeks to teach students about procedural skills, an experience or a Christmas experiment will not do the job. On the other hand, vague problems, meta-tasks and investigations might all serve this purpose, but other things are going on which will potentially prevent the students from seeing this as the purpose of the task. If you as a teacher aim for your students to learn a skill in the procedural domain, then the more obvious choice is an exercise labwork. This argument is identical to the 'prime aim' discussion by Woolnough and Allsop (1985), see quotation at page 190.

Somehow the labwork types should be understood as an again larger part of the PRIME process, where additional pieces are added to it. Starting of from the experiences, only the phenomenon is there. Going on to exercises, both the phenomena and the data handling of it exist. Further for vague problems, where the translation from everyday language to physics language and back again exist and on to investigations with the full PRIME process. Meta-tasks, as being a number of things, are to some extent about understanding and questioning this process or the parts of it.

Having now developed the link between main categories of labwork purposes and labwork types, the current tradition in the Danish Gymnasium is to be investigated in order to link specific labwork activities to their specific labwork purposes. To do this, the labwork activities are categorized according to the six recognized labwork types, and this then gives their potential purposes. To further gain insight of the potential learning outcomes, each of the labwork activities are linked to the sub-categories of the mapped purposes, such as these are described in the previous chapter.

6.3 Series of typical practical works

This section sets out to describe which labwork activities the students in physics of the Danish Gymnasium experiences during their education. This result in an exemplary list of labwork activities a typical physics student experience throughout the three years of the Gymnasium.

Naturally, an underlying assumption is that such a typical series exist. To argue for this assumption and to develop a typical series a number of labguide series has been collected through internet searches, data-base extracts and collections among physics teachers in the Gymnasium.

But before searching through the many resources for developing a typical labwork series, the physics curriculum for the Danish Gymnasium has to be investigated to understand which core topics the different levels operate with.

Which intentions the curriculum poses for labwork, both in relation to skills and content, and at what level are already discussed in section 5.1.2.

6.3.1 Core topics of the curriculum

The curriculum of the Danish Gymnasium describes a number of core topics for each level. These topics overlap, such that e.g. the energy concept is to be taken up in all three years on a still more advanced level. In table 6.9 the core content of the three level C, B and of the physics classes in the Gymnasium can be seen.

Besides the core content dictated by the curriculum, each level is dedicating a part of the time for a supplementary topic or topics, which should be chosen to acknowledge both the general and vocational goals explained in the curriculum (see section 5.1.2), but also containing current and societal issues including aspects of sustainable development of physical or technological kind. For these supplementary topics, respectively 40%, 25% and 30% of the time is dedicated for it. The topic of physics in the 21st century is changing each year and is determined by the Ministry of Education.

Table 6.9 Core content of the three levels of the physics classes in Danish Gymnasium, according to Bekendgørelse (2006).

Core content	*C*	*B*	*A*
The contribution from physics to the scientific world view	X	X	X
• Main features of the present physical description of the Universe and its evolution, including the principle of cosmology and the expansion of the Universe	X	X	X
• . . . including the red shift of the spectral lines		X	X
• Earth as a planet in the solar system as basis for explaining directly observable phenomena of nature	X	X	X
• Atoms as basis for explaining macroscopic properties of matter	X		
• Natures smalles building blocks, including atoms as the basis for explaining macroscopic properties of matter and the formations of the elements		X	X
Energy	X	X	X
• Description of energy and energy transformation, including power and efficiency	X	X	X
• Examples of types of energy and a quantitative treatment of the transfer between at least two types of energy	X		
• Kinetic and potentiel energy in the gravitational field close to Earth		X	
• Internal energy and energy relations at changes of temperature and states of matter		X	X
• Equivalence between mass and energy		X	X
Electric circuits		X	X
• Simple electric circuits with stationary currents, described by current, voltage, resistance and energy transformation		X	X
Sound and light	X		
• Basic properties: wave length, frequency and speed	X		
• Experimental determination of wave length	X		
• Physical properties of sound and light and their connection to sensory perception	X		
Waves		X	X
• Basic properties: wave length, frequency, speed and interference		X	X
• Sound and light as examples of waves		X	X
• The electromagnetic spectra		X	X
Quantum physics		X	X
• The structure of atoms and nuclei		X	X
• Energy of photons, emission and absorption of radiation in atomic systems, spectra			X
• Emission and absorption of radiation in atomic systems, spectra		X	
• Energy and momentum of photons, particle-wave duality			X
• Radioactivity, including types of decays, activity and the law of decay		X	X
Mechanics		X	
• Kinematic description of motion in one dimension		X	
• Concept of force, including gravity, pressure and buoyancy		X	
• Concept of force and laws of Newton, including pressure, buoyancy and friction			X
• Newtonian laws on motion in one dimension		X	
• Motion in one and two dimensions, including projectile motion and uniform circular motion			X
• Conservation of momentum, including elastic and inelastic collision			X
• Law of gravity and motion around central body			X
• Force and energy properties at a harmonic oscillation			X
• Mechanical energy in a homogenous gravitational field and for a gravitational field around a central body			X
Physics in the 21st century			X

Laboratory work is not dictated for each of the core topics, but approximately 20% of the confrontation time should be spend in the school laboratory, and therefore table 6.9 will give good indications of which topics the labwork activities could cover.

6.3.2 Collected labguides

Labguides have been collected both by personal communication with a number of teachers, but also by searching through the web-pages of the association of physics teachers, various Gymnasiums and web-pages of physics teachers. But it has shown most useful to search through web-based databases where students upload their school assignments, including their lab reports. These web databases[2] give access to information such as the school level, the upload date, and often even the grade given for the report. But most important, this gives access to information of which labwork activities are most often done in the Gymnasiums around Denmark, and has been the main entrance for developing a typical series of labwork activities. These databases are 'honest' in the sense that students upload their assignments based on how proud they are of their work - or which grade they received for the work - and not on the teachers' likes or dislikes of making the labwork public, which could be a constraining factor when receiving the labwork series directly from teachers.

Collections among the teachers have though been useful both for seeing which labwork activities they are using, but also as a reference for detecting how many labwork tasks the students typically perform during the three years of the Gymnasium (this information cannot be extracted from the databases). In the first year of the Gymnasium, collections among several teachers indicate typically 6-7 labwork activities in the physics classes of varying length. In the second year, students typically do a few extra (7-9). And the third year the number is slightly smaller (6-7), since more time is spend on the SRP[3] and unique open-ended labwork activities developed on the basis of the students' personal interests.

By searching through various databases for most often used labwork activities, there is naturally the risk of misinterpretation. E.g. it is possible that the most common way of doing labwork activities is by using 2/3 of very often used labwork activities and 1/3 of innovative and different labwork activities. The latter will by use of the student databases never be detected as common, since these types of labwork activities will maybe only occur once in the databases. But through collecting series from teachers and schools, this concern has shown not to be of significance. This is backed up by the databases, since when looking

[2] E.g. www.studieportalen.dk, www.studienet.dk, www.opgaver.com and www.aflever.dk.

[3] Studieretningsprojekt: Individual student project to be done in their branch of study (cross-disciplinary).

through all uploaded physics assignments, only very few stand out as significantly different.

As investigating the labwork activities used in the Gymnasium, each of the most common ones are all of the guided type most familiar with the *exercises* (or closed labwork activities), such as described by Woolnough and Allsop (1985) and Christiansen et al. (2010). According to the developed link of labwork types and general labwork purposes at table 6.8, these types of labwork activities serve the purposes of the procedural skills domain. Especially in the A-level at the third year, other types of labwork activities could be used (vague problems and investigations), as used in e.g. the SRP tasks. But as these are taking another educational role, and each are specifically defined for the individual student, these type of tasks are not taken up here. But their potential purposes can be detected in table 6.8. Also, since the students do typically not hand in reports on 'experience' labwork activities (aiming at conceptual purposes), these do not exist in the data set.

Having investigated all uploaded physics reports from the Gymnasium at 'studieportalen.dk' done within the 2005-reform and from the last year at 'studienet.dk', a good indication of the used labwork activities are given. 'Studieportalen.dk' distinguishes between school level and school year, whereas 'studienet.dk' does not. On the other hand, 'studienet.dk' is by far the most popular data-base with most uploaded assignments. In table 6.10 the results of the search can be found, showing the most commonly used labwork activities and their spread on class levels.

Each of these labwork activities is further investigated in section 6.4, where their are linked to the sub-categories of the procedural skills domain.

For the case of the C-level the efficiency labwork, the heat capacity of a solid and water, the specific melting heat of ice and the specific evaporating heat of water are often somehow combined, e.g. combing the efficiency with the heat capacity of water, or combining the specific melting heat of ice and the specific evaporation heat of water.

For the case of the B-level, the two radioactivity labwork activities are often combined.

When going through the labwork databases, it becomes obvious how teachers interchange labwork activities if they are sure of having the students at more than the C-level. Also it the students have not had the time for having a C-level relevant labwork, this is moved on to the B- or A-level.

There is a potential bias, since it might be more common among students from one class to upload their lab reports than students from another class.

In appendix E.1 tables displaying the headlines of the most typical physics labwork activities for each of the three levels are seen along with their connection

Table 6.10 The most commonly used physics labwork activities of the Gymnasium found on the two most popular student assignment data-bases in Denmark.

	Labwork	Studieportalen			Studienet
		C	*B*	*A*	
Level C	Density of solids or liquids	6	2		17
	Pendulum	1	1	1	10
	Heat capacity (solids)	10	3		49
	Heat capacity of water	18	3		25
	Specific melting heat of ice	6	1		49
	Specific evaporating heat of water	2			20
	Efficiency of e.g. coffee maker	15			56
	Optical grating/distance of furrow of cd	18	5		60
	Standing waves in tube /speed of sound	4	1		18
Level B	Halftime (radioactivity)	3	10		16
	Halfwidth (radioactivity)	4	8		43
	Spectral analysis	3	4		20
	Standing waves on string	3	4		30
	Ideal gas	1	1		14
	Free fall (ball)	2	1		25
	Friction (incline or drag)	2	1		9
	Air track (energy cons., Newton 2)	2	2		9
	Electric resistance (Ohm's law)		4		21
	Joule's law	1	4		10
Level A	Air resistance with cake tins			2	2
	Projectile motion	1	2	2	10
	Momentum			3	1
	Uniform circular motion			2	5

to the core content of the curriculum, see table E.1, table E.2 and table E.3.

6.4 Linking specific labwork activities to specific labwork purposes

Having now described the labwork types and how they relate to the general purposes of labwork activities, it is time to investigate the most common labwork activities in the Gymnasium physics classes of today and their link to specific purposes. In the following, each of the specific labwork activities recognized as typical are discussed in relation to their specific potential learning outcomes (a few examples is given here, and the rest in appendix E.3). Since all of the common labwork activities bare most resemblance with the *exercise* labwork type, according to table 6.8, their most prominent purposes are within the procedural skills domain. As this domain was investigated in depth in section 5.4, the there recognized sub-skills are those which should be linked to the specific labwork activities.

Labwork activities having identical headlines might be different in their apparatus choice, measuring design, data treatment, etc. The link of procedural sub-skills and specific labwork activities are therefore highly influenced by the specific labguide. Therefore it was chosen to use labguides downloaded from the official Danish web-portal for education: 'www.emu.dk', which has a sub-unit for Danish Gymnasium physics education[4] produced in cooperation with the Danish Centre for Teaching Resources [5]. Working with the discipline associations and the Ministry of Education, these web-pages are developed and maintained. The there found labguides are open to all users and are an obvious choice for Gymnasium physics teachers in finding inspiration to labwork activities.

In the following, each of the labwork activities is investigated in order to link them with the sub-skills of the procedural domain. As an assistance, a full list of these sub-skills can be found in appendix E.2. After going through each labwork, the results are summarized in table 6.11 at page 211. For most readers - I would expect - reading through a few labwork examples is enough to gain the picture of the work, and therefore only a few examples are presented here, and the rest can be found in appendix E.3. The analysis of each specific labwork can then be further investigated, when particular interests occur.

6.4.1 Examples of labguide analysis of common labwork activities

Tree labwork activities - all from the C level - have been chosen to provide the reader with examples of the work of linking common labwork activities with the sub-skills of the procedural domain.

[4] 'http://www.emu.dk/gym/fag/fy/index.html'
[5] Center for Undervisningsmidler

Density of solids or liquids

The labwork is described in the labguide as having a four-fold aim: (1) to learn how to collect measurements and gain results, (2) to handle measurements in a graphical way, (3) become confident with the concepts of proportionality and linearity, and (4) to determine the density of alcohol. A copy of the labguide can be found at figure E.1-E.2 in appendix E.3. This labwork is described as introductory.

The labwork is done by placing a measuring jug on a weight, and determine the mass without alcohol. Then a small amount of alcohol is poured into the jug and the mass and volume are determined. The process is repeated a number of times.

For the data treatment, three suggestions are made. Firstly, the density is calculated as the measured mass subtracted the mass of the jug divided by the volume for each measurement, and finally the average is found. Secondly, the measured mass subtracted the jug mass is plotted against the volume. The density is found by a best proportional fit. Thirdly, the measured mass is plotted against the volume, and the density is found by a best linear fit. The results of the three methods are compared to each other and a table value, and the percentage-wise deviation should be calculated. Finally the students are asked to account for the sources of error.

As for the sub-categories of the procedural skills, for those associated with design, the labwork might serve the purpose of *variable identification*, since the students is provided with the opportunity of recognizing the independent variable (volume) and dependent variable (mass), and to some extent understanding how they can interchange roles, since they are bound together with a physical bond of the density value. *Fair test* is not relevant, since only the named variables have the opportunity of coming into play. *Sample size* could be touched upon when deciding upon the number of experiments, understood as how much alcohol to add at a time. *Variable types* are most likely not addressed in this labwork.

For those associated with measurement, the *relative scale* does not make sense for this labwork. *Range and intervals* are on the other hand relevant, since the students are to determine which values of the volume, they are to measure upon. Since the total volume of the jug will set a faster limit on the measuring interval than the weight, along with the fact that the accuracy of the jug scale and weight will not set an unacceptable limit to the density measure accuracy, issues related to the *choice of instrument* will most likely not come up for this labwork, but the labwork holds the potential. *Repeatability* is not addressable for this procedure. As for the case of *choice of instrument*, the issues of *accuracy* and *uncertainties* could be brought up, but are in this labguide not addressed.

For the case of those associated with the data handling, *tables* are addressed especially for the first data treatment. As *variable types* were not addresses, so is neither *graph types*. *Patterns* are of great significance in relation to both proportionality and linearity. The *equation translation* is also included, but the labguide takes care of the *units* part. As was the case of the *fair test*, *multivariate data* are not addressed.

For those associated with the evaluation of the complete task, the *reliability* could be is included. The students are asked to account for their sources of errors, also if their data is close to the table value, placing some emphasis on *uncertainties and errors*. The *validity* is not brought up.

As the labwork leads on to a report, the communication skills are included. This will be the case for all of the following labwork activities, and it will not be commented upon for the rest.

Pendulum

The purpose of the labwork - as described in the labguide - is to investigate how the period of a pendulum depends on the mass of the oscillating weight, the length of the pendulum and the amplitude. As was also the case of the density labwork, this is described as an introductory labwork. See figure E.3 at appendix E.3 for a copy of the labguide.

The labwork is done by placing a small, heavy weight suspended by two strings to ensure a stabile one-dimensional oscillation. The period of the pendulum is found by measuring 20 oscillations in order to decrease the uncertainty. Three measuring series are to be done: (1) Varying the amplitude (but though not measuring the amplitude size) and keeping the mass and length constant. (2) Varying the length and keeping the mass constant. (3) Varying the mass and keeping the length constant.

For the first measurement no data handling is intended, since it is expected the students will see how the period is independent of the amplitude. For the second measuring series, the period is to be plotted against the length, and the students are asked to conclude on the relation between the period and the length. For the third measurement series, the relation between the period and the mass of the weight is to be determined in a non-declared way. As a conclusion, the students are asked to construct an equation to express the connection between the period and the three variables.

This labwork serves a number of procedural sub-skills. For those associated with design, *variable identification* is especially significant, since the students are asked to differentiate between the independent variable to alter, the controlled variable, and the dependent variable to measure. Also for this experiment, the independent and controlled variable swap roles during the experiments. This also plays in on *fair test* understanding. To be able to answer the questions posed for the second and third measuring series, the students also need to be able to understand the *sample size* and its relation to answering the questions. *Variable types* are not addressed.

For the case of those associated with measurement, only the *range and interval* comes into play, since this labwork builds upon an inductive idea, wherefore the students most likely will not engage in any type of discussion concerning *accuracy*, *repeatability* and *uncertainties*, as well as *relative scale* and *choice of instrument*.

For those associated with data handling, the sub-skills of *tables*, *patterns* and *multivariate data* come into play, and especially the latter two are relevant in relation to this labwork. The sub-skills of *units* and *equation translation* will most likely not be concerned, again due to a somehow theory-independent approach. Since the *variable types* are not addressed, neither is the *graph type*.

For the case of those associated with the evaluation of the task, in the labguide itself these types of skills are not addressed.

Heat capacity (solids)

The purpose of the labwork - as described in the labguide - is to determine the specific heat capacity of aluminium. A copy of the labguide can be found in figure E.4-E.5 at appendix E.3.

The labwork is done by placing an aluminium block in boiling water to make sure the block is 100 degree Celsius. The block is then moved into a known amount of water in a calorimetric bowl with a known temperature. The final temperature is determined as the highest measured temperature. The experiment is repeated three times, and information is noted in the pre-printed table.

Based on the principle of energy conservation and the measured quantities (the mass of the water m_w, the mass of the aluminium block m_a, the mass of the inner piece of the calorimetric bowl m_{cb}, the initial temperature of the water T_i, and the final temperature of the water T_f) the specific heat capacity of aluminium c_a can be determined.

$$\begin{aligned} 0 &= \Delta E_a + \Delta E_w + \Delta E_{cb} \\ 0 &= m_a \cdot c_a \cdot (T_f - 100 \circ C) + m_w \cdot c_w \cdot (T_f - T_i) + m_{cb} \cdot c_{cb} \cdot (T_f - T_i) \end{aligned}$$

The specific heat capacities of the water c_w and the calorimetric bowl c_{cb} are to be looked up in a data table. Based on this the specific heat capacity of aluminium is determined and compared to the table value.

For this labwork the *variable identification* is quite important, since a large number of quantities and variables are in play here, and it is not obvious from looking at the equation which role the specific heat capacity of the aluminium, water or the calorimetric bowl material holds. The three other concepts of evidence associated with design (*fair test*, *sample size* and *variable types*) are not addressed in this labwork.

For those associated with measurements, the *relative scale* ought to be addressed in relation to the amount of water to place in the calorimetric bowl - though in the labwork the water amount is dictated by the labguide. *Range and interval* is not relevant. The labguide talks about the *choice of instrument* in relation to the accuracy of the weight, but it is not addressed further in the data treatment. Since the labwork is to be repeated three times, discussion of the *repeatability* exists. *Accuracy* and *uncertainties* are not taken up.

For the case of those associated with data handling, only the skill of *units* is addressed, since the students needs to juggle between grams and kilograms, depending on the units of table values and the units measured on the weight. The rest of the data treatment is only about manipulating equations.

For the case of those concepts of evidence associated with evaluation, the students might be encouraged to discuss *uncertainties and errors*, especially if their results are far from the table value. The same thing occurs for the *reliability*, whereas the *validity* is not addressed.

6.4.2 Summary

The rest of the 23 labwork activities are in similar ways analyzed, see appendix E.3. To summarize the work of linking the most often found labwork activities with their potential learning outcomes, a overview matrix is developed, see table 6.11 at page 211.

As also indicated at table 6.7, the content of a labwork does not define the type of labwork, and therefore each of these labwork activities can be redesigned to any of the other labwork types, and thereby serving other labwork aims.

A number of these labwork activities is obviously intended by the labguide designer as a way to gain a feel for the phenomenon in play, but the entire data treatment part emphasises how the labwork aims differently.

For some of the labwork activities at B and A level, the labguides are focusing wider and are moving towards other labwork types such as vague problems or meta-tasks. Still none of them are all the way there in their formulation.

Before turning to the second research question (*Which potential learning outcomes do the laboratory work activities commonly used in physics in the Danish Gymnasium hold?*), which is an investigation of the outcomes of declaring the specific labwork aims for the specific labwork activities, some comment and reflections on this chapter and its results are in place.

Table 6.11 Link between the typical series of labwork tasks as found in the Danish Gymnasium and the sub-skills of the procedural skills domain. 'X' indicate a full argument (or fully addressed) and 'x' indicate a less profound argument (less profoundly addressed).

Specific labwork activities		Procedural skills																			
Level	Activity	Variable identification	Fair test	Sample size	Variable types	Relative scale	Range and intervals	Choice of instrument	Repeatability	Accuracy	Uncertainties	Tables	Graph type	Patterns	Multivariate data	Units	Equation translation	Uncertainties and errors	Reliability	Validity	Communication
Level C	Density of solids or liquids	x		x			X	x		x	x	x		X			X	x	x		X
	Pendulum	X	X	X			X					x		X	X						X
	Heat capacity (solids)	X				x		x	X							x		x	x		X
	Heat capacity of water	X	X		X	x	x					x	X	X		x	X	x	X	x	X
	Specific melting heat of ice	X				x										x		x	x	X	X
	Specific evaporating heat of water	x							X		x	X				x		X	X		X
	Efficiency of e.g. coffee maker	x												X		X		X			X
	Optical grating/distance of furrow of cd				x	x							x	X				x			X
	Standing waves in tube /speed of sound	x			x				x	x		X	x	X	x	X	X	x			X
Level B	Halftime (radioactivity)	x			x	x					X		X	X			X	X	x		X
	Halfwidth (radioactivity)	X	x		x	x	X	X	X			x	x	X			X		x		X
	Spectral analysis	X			X			x		x		X							X		X
	Standing waves on string	x	x		x			x		x	x	x	X	X	X	x	X	x	x		X
	Ideal gas	x	x										x	x		x	x				X
	Free fall (ball)							x				X	X	X			x				X
	Friction (incline or drag)											x	x	X			X	x			X
	Air track (energy cons., Newton 2)										X	x	x	X			X	X	X	x	X
	Electric resistance (Ohm's law)	X					X	X				X		X		X	X	x	X		X
	Joule's law	x	X			x		x						X	X	X	X		x		X
Level A	Air resistance with cake tins											x	x	X	x	x	X				X
	Projectile motion	x					X	X	X	x		X		X		x	X		X		X
	Momentum							x		X	X	x		X				X	X		X
	Uniform circular motion	X	X				X	X	x	X	X	x		x	x	x		X	X		X

6.5 Summery and reflections

This work of answering the first research question ended out in two matrices. The first (table 6.8) is of a normative type, stating how the six identified general purposes of labwork activities should be matched to six different types of labwork activities. Underlying this is the idea that all six labwork types should be represented in physics education to gain the learning which labwork activities potentially serve.

When claiming the one-to-one link between the general purposes and the labwork types, one could argue that this is a ring argument; each of the labwork types is designed to serve each of the labwork purposes, and therefore nothing is said. I hope the description of each of the labwork types has proved this wrong. Still, if the ring argument is retained, I claim there still is a point to it, since by clarifying and articulating how different labwork types serve different purposes, the belief that any labwork teaches students all purposes inevitably is argued against.

Besides the one-to-one correspondences between labwork types and labwork aims, the table has additional marks in parenthesis. These should be interpreted differently. A specific labwork serves a specific purpose, but it also holds the potential to serve additional purposes. But if any of these additional purposes really is the main purpose of the task, one should consider changing the labwork type.

This relates to the kind of taxonomy there exist in the purposes of the different labwork types. A *Christmas experiment* only serves the affective domain, whereas an *experience* both serve the conceptual and affective domain, and again an *exercise* serves both the procedural skills domain, the conceptual domain and the affective domain, etc. By use of this chain of ideas, one could think that the labwork type with most potential purposes - *investigation* - is a sure way of gaining all purposes. This is a misinterpretation of the intentions. Doing investigations is a complex affair which does not make sure all of these other purposes are met - though they potentially could. As the case of the PE physics labwork (see section 4.1.3), there for sure is the possibility for student frustration and poor learning outcome embedded in these types of very open tasks if not handled carefully. Much could thought be gained when articulating the purposes of the labwork in its introduction.

The second matrix (table 6.11) has a different aim. This investigates the labwork activities that currently are used in the Danish Gymnasium physics classes, and tries to investigate the potentials that lies in them in the frame that is set for them by teachers (and the traditions) already. I am not trying to change the labwork activities, but investigate them under the premises, which are already there. Since all of the detected labwork activities are fairly guided, the first matrix proves how these serve the skill domain foremost. But the procedural skill domain is a rich category, and by unfolding it and linking the sub-categories of the procedural skill domain with the specific labwork activities, the labwork can be used in their original form, but now with much more clear-cut goals to chase for.

The work of filling out the scheme is done for several reasons. Firstly, to show it *can* be done, and therefore proved that there exist reasonable purposes for the currently labwork activities in the form they are in (often in literature guided labwork activities are looked down at to such an extent that one could be brought to believe they serve no purposes at all). But also because it can provide others with either a solution or a process of rethinking labwork activities and their purposes. Thereby it becomes clear where the task design provides students with learning hurdles, or where these are removed. It serves as an eye-opener to the issues addressed concerning the obstacles dislodgement, as unfolded to be a main problem in labwork practise (see section 4.6.2). By filling out the matrix (or reading the here already done work), it becomes clear which particular skills the labwork could serve and does serve, and which skills are either not relevant for the labwork or are removed as an aid to the students.

Each of the marked out links should not be understood as rock solid. Small changes in the labguide or additional comments during the teacher's introduction might rotate the markings. Still the analysis of each labguide in relation to the sub-skills of the procedural domain is consistent throughout the 23 labwork activities, and the analysis also provides a deeper understanding of each of the sub-skills when exemplified.

As seen the *validity* category is quite under-used, since this skill suits better another type of labwork, such as vague problems and investigations. Therefore, retrospect this sub-skill does not fit very well into the categories of sub-skills for the procedural domain. In the same way one could argue for deleting other of the sub-skills.

As one could argue that some of the sub-skills should be deleted, one could also argue for the need of additional sub-skills. I have built this upon the work by Gott and Duggan (1995), but have felt the need to add some categories to their list. After having analyzed all labwork activities, I can see how some sub-skills could have been added, e.g. by splitting the *patterns* skill into a graph pattern and a table pattern, and maybe even a deviation pattern - though the latter starts to overlap with the *uncertainties* category.

Also, one could argue the matrix miss a third axis. As each of the sub-skills listed cannot be categorized as something which is either fully grasped or something not ever considered, the level of required understanding might needs its own third axis. E.g. for the fair test sub-skill, first level might be to recognize or recall the term and being able to state its meaning, and from there on to understand fair test, to apply fair test in unfamiliar situations and to synthesize fair test in problem solving (if the Bloomian taxonomy mentioned in table 5.5 is to be used). I have deliberately not included this third axis in the scheme. Firstly due to the table being enough information-packed already. Secondly, because the task of investigating each of the sub-skills in relation to such a taxonomy categorization would be very difficult and in-consistent. And thirdly, because the required taxonomy level would only for a very few of the labwork activities be possible to extract precisely on the basis of the labguide. As discussed a number of times for the specific labwork activities, a student could engage in beneficial reflections of a specific sub-skill, but often the design of the labguide does not require it for solving the task. But the discussion of the taxonomy level of the skills is definitely interesting and relevant, and that is why it was taken up when discussing the specific labwork.

Having argued for the matrix in a number of ways, finally the second matrix can be understood as a way to exemplify the points of the first matrix. As previously argued, results and reflections in physics education research are often difficult to pass on from writer to reader, and by doing this exemplification, hopefully the reader will have a better impression of what is meant with table 6.8.

Besides these reflections directly related to the results, a few additional observations should be mentioned.

Firstly, when reading through the data-bases of uploaded assignments in physics, it becomes obvious how tradition-bound the Gymnasium is compared to other school types teaching physics. In elementary school, besides working with other topics, the assignments are longer, filled with background research, with few experiments focusing on the phenomenon and with very little data handling (closer to an essay assignment than a physics report). For HTX[6] the assignments are very individual and are centred around special interests of the students (or their teacher), and are quite project-oriented. Data handling is important to prove a point and to validate a hypothesis, and not in itself such as it often are seen for the Gymnasium tasks.

Secondly, when looking through the data (though the statistical material is not sufficient), some tendencies occur, when looking at the temporal development of the addressing of the sub-skills. The data can be found in table 6.12. Counting out the number of marks for the four different concepts of evidence (associated with design, associated with measurement, associated with data handling, and associated with evaluation of the entire task), some tendencies emerge. For those associated with design, these skills are addressed more often at the C-level, decreasing throughout the B-level on to the A-level. For those associated with measurement and data handling, the opposite tendency occurs,

[6] A Gymnasium specially addressed for students interested in technology and engineering.

Table 6.12 Fractional count-out of the markings of table 6.11. 'xX' indicates adding the 'X' and the 'x'.

	Design			*Measurement*			*Data handling*			*Evaluation*		
	x	X	xX	x	X	xX	x	X	xX	x	X	xX
C	0.78	0.89	**1.67**	1.33	0.44	**1.78**	1.11	1.56	**2.78**	1.11	0.56	**1.67**
B	1.00	0.50	**1.50**	1.00	0.70	**1.70**	1.30	2.50	**3.80**	0.80	0.50	**1.30**
A	0.25	0.50	**0.75**	0.75	2.25	**3.00**	2.50	1.50	**4.00**	0.00	1.25	**1.25**

and the sub-skills are increasingly more used throughout the three levels. For those associated with the evaluation of the task, the tendency again is that these skills are decreasingly addressed. This is expected, since at the first year the curriculum places less emphasis on the data handling 'calculus' part of the experimental work, and more on understanding how the knowledge of physics emerges. Throughout the B- and A-level more and more emphasis is placed on those skills relevant for those wishing to pursue an academic education within physics, where they obviously need well-trained skills in the modelling and data handling. Thereby the overall results stem with the expected, underlining the validity and reliability of the results. This simple analysis does not take into account the taxonomic level of the skills, as these obviously increase progressively throughout the tree levels, but merely shows which skills that are addressed.

Thirdly, it should be made clear that the philosophies behind the two matrixes are quite different. The first could both be thought of as a teaching aid, but equally likely as a basis for a normative discussion of labwork activities for the case where the teaching tradition are to change, such as during the making of reforms or new educational organisations. Opposed to this, the second matrix is true to the current tradition, and should not be used as a normative tool in the same way as the first matrix. The second matrix serves the role of enhancing reflections of specific purposes for specific currently used labwork activities. I believe both philosophies have a significant role to play in physics education research. The first, because if researchers within this field are not to consider what would be the better choices to make if things are put upside down, then what would guide the reform makers if such a situation was to occur? And the second, if researchers only were to deal with imagined and ideal situations, the (already large) gab between research and practice would persistently increase in size.

Part IV

Declaring intended learning outcomes

7 Reflections on the impacts of declaring intended learning outcomes

This short chapter deals with reflections of the second research question "*What is (if any) the impact on the students of a declaration of the teacher's intended learning outcomes of the specific labwork?*". In the previous part, a linking of the purposes of practical works with the specific labwork activities of physics classes was developed. This chapter and the following investigate the importance and use of this work.

Many previous researchers concerned with practical work in school science have come up with the solution to the problems of practical work by underlining the importance of explaining to the students, what kind of practical work they are doing, and why they are doing it. For example:

> The student needs to be as aware of the aims of the practical as the teacher is. The student needs to be clear not only about the specific objective of a practical, but also about the over-riding aim, for that will need to be stated, such that the student may know how to approach the task.
>
> (Woolnough and Allsop (1985), p. 60)

and

> If students engaged on laboratory work were asked 'What are you doing?', 'Why are you doing it?' and 'What has what you are doing got to do with science or your everyday life?', what responses might you expect? Answers given to these questions have indicated that most students have only a limited idea of what they are doing, and few can explain why (Baird 1984).
>
> (Baird (1990), p. 184)

and

> ... we believe that teachers should be open and honest with pupils about which type of practical work they are doing and why. We advocate that students should be made aware of the different kinds of practical work they do and the purpose of this practical work. In short, teachers should explain to students what type of practical work they are doing and why.
>
> (Nott and Wellington (1996), p. 807)

and

> Each type of practical work serves a different purpose: different type, different aim [...]. We need to convey this to pupils; for instance, if they are going to replicate what someone already knows, tell them: don't kid them that they are discovering something.
>
> (Wellington (1998b), p. 12)

and

> ...I have tried to show, using examples, the significant difference between the things which are said about the role of practical work in science education and the purposes which are implicit in the thing which are actually done. There is more need, I think, to change what we say than what we do - though a clearer understanding of what practical work can and cannot do might also lead to better designed and more effectively targeted practical works.
>
> (Millar (1998), p. 30)

Based on these quotations it seem obvious to discuss the learning goals of lab-work activities. Still it seems worthwhile to place these discussions in a larger picture. Discussing purposes opens up for discussing metacognition, which again open up for conceptual change and constructivism discussions. But the arrows also points the other way; that is, believing in the importance of metacognition this work of investigating the impact on declaring the intended learning outcomes of a task is important, and even more so than from the above quotations.

Relating metacognition to this work services metacognition in the sense that in believing in the found results of this study and its importance it follows that one believes in the importance of enhanced metacognition. And metacognition also serves this work in proving this study with concepts, research tools, analysis tools, etc., but also provides the opportunity to discuss this study in a well-established research frame.

Relating back to the discussion of frameworks given in section 2.1.2, metacognition (and the appurtenant epistemology and research traditions) serve the role of a scaffold for this study, as well as the findings of this study serve the role of a scaffold for metacognition.

In the chapter the research question is discussed in the light of the concept of *metacognition*, which firstly is used to place this part of the study in a broader context, but even more important it is found relevant in order to clarify the underlying (and partly hidden) assumptions about teaching and learning, on which the research question is posed. In the words by Lester (2005), such as discussed in section 2.1.2, the concept of metacognition acts as a conceptual framework and thereby a scaffold for justification of the research choices, and not as a theoretical framework on which the research is build.

This chapter contains four sections. The first section 7.1 investigates the concept of metacognition. As this is developed, metacognition is linked to constructivism and conceptual change, where the latter is further investigated in section 7.2. Thereafter in section 7.3 the outcomes of studies working on enhancing the metacognitive level in the learners is reviewed. Finally in section 7.4 the links between the concept of metacognition and this work as well as the reflections supported by the ideas of metacognition are given.

7.1 The concept of metacognition

When posing a research question like "*What is (if any) the impact on the students of a declaration of the teacher's intended learning outcomes of the specific labwork?*", obviously there is some underlying understandings of teaching and learning. E.g. there is the underlying premiss that a higher awareness and reflections of the potential purposes of a teaching/learning task, both for the teacher and the students, will cause enhanced outcomes of a teaching/learning activity

In chapter 4 data concerning the teachers were presented. In this part the focus is on the students. Focusing on the students' perception, 'taking in', and reaction to the teachers intentions could be viewed within the branch of (science) education research known as *metacognition*.

The concept of metacognition typically covers a large range of issues from awareness of the intentions and potentials of a teaching/learning task towards awareness of the student's own previous beliefs and ideas and the potential need for refining them, including ideas of how to make his or her own learning more effective.

Baird (1990) describes metacognition as: "Metacognition refers to the knowledge, awareness and control of one's own learning." (Baird (1990), p. 184) With *metacognitive knowledge*, he understand the student's knowledge about learning, about effective learning strategies and personal learning characteristics, which all are expected to influence the learner's responsibility and control over their own learning. *Metacognitive awareness* and *metacognitive control* he describes as: "...learning outcomes associated with certain actions taken consciously by the learner during a specific learning episode." (Baird (1990), p. 184) The level of *metacognitive awareness* relates to the ability to (consciously) ask and answer various evaluative questions regarding the cognitive processes taking place during the specific learning episode. *Metacognitive control* then deals with the learner's ability to consciously change their process (approach, progress and completion) based on the found answers.

Kung and Linder (2007) describes metacognition as "...cognition about cognition [...] understanding, monitoring, and controlling one's knowledge and strategies." (Kung and Linder (2007))

Gunstone (1991a) develops this further by describing metacognition as:

> [L]earners are appropriately metacognitive if they consciously undertake an informed and self-directed approach to recognizing, evaluating and deciding whether to reconstruct their existing ideas and beliefs. By informed, I mean recognize and evaluate, with an understanding of learning goals, of relevant uses of the knowledge/skills/strategies/structures to be learned, of the purposes of particular cognitive strategies appropriate to achieving these goals, of the processes of learning itself.
>
> (Gunstone (1994), p. 133)

As seen, he both uses metacognition as an understanding of the learning goals - which could both be knowledge, skills, strategies and structured, but also being aware of the students' own best process to reach these goals.

He unfolds the first part of understanding the learning goals by stating: "Metacognitive awareness includes perceptions of the purpose of the current teaching/learning activity, and of personal progress through the activity." (Gunstone (1994), p. 134), and describes a metacognitive learner by a person asking questions like "'What am I meant to be doing?', 'Do I know what to do/write/look for?', 'What is the purpose of this task?', 'Have I done everything necessary?', etc." (Gunstone (1994), p. 135)

Gunstone points out very often students do not know the purpose of instruction in class, and sees metacognition as a process of reflection upon and taking action about their own learning, wherefore metacognition can be seen as a potential solution to the problem.

A number of research projects have been working on enhancing students' level of metacognition, e.g. the PEEL-project[1] (Baird 1990; Baird and Northfield 1992), which has also inspired Danish physics education research, e.g. Dolin and Ingerslev (1994); Dolin (2002).

Based on the descriptions of metacognition, this work can be seen as a sub-category of the metacognition ideas. The ideas of metacognition will be placed in a more general picture of science education research. According to Gunstone (1994, pp. 133-134) metacognition is strongly intertwined with the research tradition of conceptual change and with the constructive theory about the nature of learning Gunstone (1991a). The link between conceptual change and metacognition is discussed below. The link between constructivism and metacognition is almost intertwined per definition, since metacognition is described as the learner's decisions about reconstruction knowledge, and constructivism for short could be understood as "...that the learner constructs his/her own understanding from the totality of the experiences which he/she sees as relevant to the concept, belief, skill etc., being considered" (Gunstone (1991a), p. 132).

[1] Project for Enhancing Effective Learning

7.2 Research traditions

In the review article about learning science in the 'Handbook of Research on Science Education' Anderson (2007) discusses the difficulty of manoeuvring in the field of science education research:

> The diversity of methods and viewpoints can make reading research on science education a frustrating experience. There seem to be no rules that everybody follows, no beliefs that everyone shares, no findings that everybody agrees on. Where is the order in this welter of confusing findings? How can we say that we are making progress in the field?
>
> (Anderson (2007), p. 3)

His way out this potential drowning pit is by recognizing the trends and traditions which divide research in science education into sub-groups wherein researchers hold common beliefs, grow increasing understanding within their shared research tradition, and build on each other's work.

Within the subfield of science education research investigating students' learning of science, Anderson (2007) identifies three main trends: the *conceptual change tradition*, the *sociocultural tradition*, and the *critical tradition*. Each of these three groups can naturally be divided into subgroups, which might be argued to be individual trends on their own. Anderson's arguments for this division are that the three groups hold different beliefs about the nature and purposes of science education research.

7.2.1 Conceptual change tradition

The conceptual change tradition has evolved on the work of Piaget. Conceptual change is based on the foundations of constructivist learning and an epistemological view of the nature of science (Georghiades 2000, p. 120). In this tradition the learning problems addressed are described in conceptual terms and focuses on a specific scientific domain (Anderson 2007, p. 7). Typically research done within this tradition aims for identifying and understanding a learning problem, finding a strategy to help students overcome the learning problem, and proving the worth of the strategy by some kind of comparative study.

The conceptual change trend has for a number of years been very popular in the science research community for several reasons: Firstly, it is a chase for the solution to the obvious problem of why students are not learning what the teachers/curriculum intend them to learn by identifying the students alternative frameworks and address them explicitly in the teaching/learning situation. Secondly, researchers have over time developed a number of tools (conceptual and methodological) to pursue this enterprise. Thirdly, this type of research demands the researchers to possess a profound amount of knowledge of the science content in play, which fits very well with the fact that researchers often come with a strong background in the relevant science discipline. Fourthly, this type of research has shown to have the opportunity to influence political decisions concerning school science.

On the other hand, much of the research done in the conceptual change tradition have merely served as an existence proof of an enhanced learning outcome, when implementing the developed teaching strategy. Also, this type of research has shown to have severe problems in spreading the research findings to a large number of practitioners.

7.2.2 Sociocultural tradition

The sociocultural tradition has emerged based on the ideas of Vygotsky, focusing on how students learn from their participation in activities with other people (Anderson 2007, p. 14). Within this tradition researchers search to understand the culture and language of scientific communities, how people socializes into science cultures, learn to use practices and resources to reason scientifically and solve science problems, etc. Typically, research in the sociocultural tradition aims for clarifying the theoretical approach, developing research methods and empirical data for sheading light on the research question and reflect upon the possible implications for science education.

Even though the sociocultural ideas have existed for a number of years, it is more recently this types of research have found place in science education. Sociocultural research has proven its worth in firstly adding and deepening the insight into the reasons to students' problems with learning science, such as hidden cultural conflicts, and secondly revealing

> ... the many ways in which scientific discourse communities are built around language, values, and social norms of their (mostly European middle class) members. Similarly, schools privilege the language, values, and social norms of their (mostly European middle class) teachers. Thus middle-class European children enter school with significant advantages over children from other social and cultural backgrounds.
>
> (Anderson (2007), p. 20)

On the other hand, sociocultural research has proven to hold difficulties in influencing policy makers, both due to its shorter history in science education, but mainly because the methodologies of sociocultural research prevent quantitative data. Also the sociocultural tradition has had difficulties in changing teaching practice, mainly because this type of research do not prescribe a reproducible practice. Finally, researchers in science education have had difficulties in familiarizing themselves with the challenges of sociocultural research based on linguistic and anthropological concepts.

7.2.3 Critical tradition

The critical tradition has emerged from the ideas of e.g. feminists' critic of science (Keller, Harding), and scholars seeking to show how dominant classes manipulate 'truth' to their advantage, including scientific truth (Foucault, Scott).

Research in the critical tradition is investigating how the conceptual and cultural conflicts (researched by the conceptual change and sociocultural tradition, respectively) are shaped, and how their outcomes are determined by power and ideology (Anderson 2007, p. 20).

For research in the critical tradition, it is seen important for the researchers to position themselves, including their own backgrounds and perspectives in the research reporting.

Critical researchers have successfully been able to develop analytical tools to question the science education system by posing claims of the school system as being very successful in doing exactly what is was designed to do: namely restricting access to the true power of scientific reasoning to a small elite (Anderson 2007, p. 25).

On the other hand research in the critical tradition has had close to no influence on either policy or practice, partly "... because critical researchers openly question the premises on which policy is made, science teaching practice is based, and science achievement is measured." (Anderson (2007), p. 25) Critical researchers also question how the gain of learning science among the weakest students will have no impact of the learning outcome among the students, which are normally strong science learners.

7.2.4 Conceptual change and this study

In table 7.1, a schematic comparison of the three main traditions of science learning identified by Anderson is seen, outlining their historical background, their view on the nature of science, their ideas about science learners and science learning, their research goals and research methods, and their ideas of improving science learning.

As becomes obvious from this way of characterizing research traditions this thesis makes use of the ideas developed within the conceptual change tradition. This clarification can e.g. be seen at the discussions in chapter 2, along with the research questions and research choices made to answer them.

I bare in mind the critical voices of the conceptual change trend, such as the underlying assumptions of viewing science sole as 'what it is', and not as a community of scientists, teachers, learners, etc. Also I have several times addressed the issues of 'proving' the worth of my research, as unfolded generally in the discussion of criteria for good research in section 2.1.1 and section 2.1.4

Taking this as the basis for understanding conceptual change, Gunstone (1991a) develops the ideas further by both understanding conceptual change as *replacement* and *addition*. *Replacement* is to be understood as the abandonment of one conception and the acceptance of another. *Addition* is on the other hand

Table 7.1 Some profound differences between the conceptual change tradition, the sociocultural tradition and the critical tradition.

	Conceptual change	*Sociocultural*	*Critical*
History	Piaget	Vygotsky	Foucault, Scott
Nature of science	Science as a theoretical dialogue with nature	Science as a discourse community	Science as inherently ideological and institutional
Science learning	Learners as rational but inexperienced learners and learning as conceptual change	Learning as control of multiple discourses	Science learning as indoctrination or the development of critical consciousness
Goals and methods	Analyzing students' conceptions	Analyzing learners' culture, language, and practices	Discovering and analyzing ideologies and power relationships
Improving	Teaching methods for conceptual change learning	Teaching methods for sociocultural learning	Teaching methods to achieve critical literacy

to be understood as the (informed) understanding of the value of the added conception in appropriate contexts. Conceptual change then

> . . . involves the learner recognizing his or her existing ideas and beliefs, evaluating these ideas and beliefs (preferably in terms of what is to be learned and how this is to be learned), and then personally deciding whether or not to reconstruct these existing ideas and beliefs.
>
> (Gunstone (1991a), p. 132)

From these ideas it becomes obvious how constructivism, conceptual change and metacognition are linked, and how they are linked to this research project.

7.3 Review of studies for enhancement of the metacognitive level

Several studies have worked on enhancing the students' metacognitive level; some reporting more success than others.

Baird (1990) puts forward how the labwork activities hold the opportunity for students to engage in independent and effective learning through purposeful enquiry, which he understands as monitoring and evaluating the nature and progress of own learning. This said, Baird questions whether this opportunity is met. To enhance the metacognitive level during labwork activities, he put forward three approaches: (1) Improve the comprehensibility of instruction (familiar terms and concepts, familiar apparatus, familiar contexts). (2) Train in deficient intellectual skills (intellectual skills deficiencies severely limit a student's ability to achieve adequate metacognition). (3) Train for enhanced metacognition (training in asking questions directing and monitoring the nature of enquiry provide the students with metacognitive knowledge).

Gunstone (1991a) reports success in the quest of relating metacognition to specific science contents. He talks about metacognitive goals of specific tasks, where these could be 'recognize and evaluate your ideas/beliefs about learning/teaching roles', 'recognize the theory-dependent nature of your own observations', etc. To foster success, though, some issues needs to be cleared: There is a need for relevant contexts, such that the metacognitive goals are relevant to the task, and the content must not to be completely unfamiliar to the learner, such that the scientific content used as a vehicle for development of metacognition is neither trivial nor too demanding. To make this balance, he states, is not an easy task.

One of the extensive studies in the field of metacognition is the PEEL project. The PEEL project develops the ideas of metacognition, and documents how learning can only take place if the learners decide to learn and do the work themselves. The results of the PEEL project are that metacognition *can* be promoted and enhanced, and when this occur it will facilitate conceptual change. It also documents how the ideas of metacognition are perceived artificial, until the students recognize how the enhanced metacognitive level are meeting their own short-term goals (White and Gunstone 1989). This metacognitive process in the learner can and should be helped forward by the teachers. This is often a barrier, since many teachers find how their finest work is to be well prepared and serve well-structured knowledge to the students. Baird and Northfield (1992) report the work of making this change and emphasises the importance of teacher cooperation and jointed reflections to enable the process.

Another large project related to enhancing metacognition is CASE[2]. The aim of the CASE study was to develop and explore an approach to improve the students' ability to learn. One of the main ideas in this study was metacognition (Adey and Shayer 1994), and promising results related to long-term effects in various disciplines were detected, though not for students below the age of 12 (Adey et al. 1989).

Hart et al. (2000) work with physics school laboratories at Gymnasium level, where they report how one of the main issues of labwork is

> One reason, among many, for this failing is that students often do not know the "purposes" for these tasks. By purposes we mean the intentions the teacher has for the activity when she/he decides to use if with a particular class at a particular time.
>
> (Hart et al. (2000), p. 655)

Taking off from this they develop a laboratory unit where the teacher's purpose was to develop students' understanding about the way scientific facts are established and not placing any emphasis on teaching the students any science

[2] Cognitive Acceleration through Science Education

content during the unit. Hart et al. describe the unit as very successful both in relation to the cognitive and affective domain.

Kung and Linder (2007) work with physics school laboratories at university level. They monitor the level of metacognitive discussions during a number of different labwork types (cook-book, cookbook with additional ‘explain’ questions, and investigations), and they find the metacognitive level is to a higher extent depending on the students of the labwork groups than on the type of labwork. This lead them to conclude that a greater amount of metacognition does not necessarily improve students’ success in the laboratory, and thereby that it is more important to consider the outcome of the metacognition and not just the amount of metacognition.

7.4 Metacognition and this work

As it has been described above, the focus on declaring the teacher’s intended learning outcomes of a specific teaching/learning task can be placed within the ideas of metacognition, and with that - according to e.g. Gunstone (1991a) and Georghiades (2000) - also conceptual change and constructivism.

As already hinted, there are several reasons to ‘enrol’ in a specific learning theory. Firstly, it places this part of the study in a broader context, and serves to answer some of the underlying questions about teaching and learning (and the role of content) which might not be directly addressed. Secondly, they have a more practical use, since they serve as a research scaffold, a name-giver for concepts not easily grasped, as well as a provider of research designs and tools for data analysis.

Up until now the presented data has been centred on the teachers and how they handle their labwork designs in relation to learning purposes. When pulling in metacognition, the focus shifts towards the students and their perception of the labwork tasks. As discussed by e.g. Baird (1990) the role of the teacher is to support and provide the students with situations for developing the metacognitive level. As the PEEL project has shown, it is possible to enhance the metacognitive level, but it demands a great effort for teachers to change their practice as well as convincing their students of the point of it. It is likely the teachers’ work on enhancing the metacognitive level works counter-intuitive to the teachers’ hold ideas about being good teachers, such as building well-structured modules around the content (White and Gunstone 1989).

The research design of this work was not - like many of the referred studies - aiming for an enhanced metacognitive level. It was not to develop teaching strategies in order to increase metacognitive discussions and reflections at the students.

Instead it is an investigation of the impact on the students as a function of the declaration level. A higher declaration level grants the students the possibility to enhance their metacognitive level, but it was not a specified task to be aware of the teachers' intentions. The students were not asked to pose questions like: 'Why are we doing this task?', 'what can we learn from this task?', 'would another task provide this better?, etc. Therefore this work is not taken the ideas of enhancing the metacognitive level all the way there, as is the case of several of the referred studies. In the next chapter (chapter 8) the cases are analyzed in order to see how aware the students are of the potential/intended learning outcomes that exist in the tasks, and how they react to it.

Gunstone (1991a) describes a study where each task has a metacognitive purpose, such as having the students: "...recognize their ideas/beliefs about learning/teaching/roles and, since this recognition is in the context of a successful alternative learning experience, to begin evaluation of these personal existing ideas/beliefs." (Gunstone (1991a), p. 137) The task is in this case concerning how gravity pulls equally on all things.

When reading this some concerns about the metacognition ideas are in place. Is a task concerning gravitational pull really the best way to learn about own ideas and beliefs of learning? Is there not a risk of clouding both the metacognitive and content-based goal of this task, when forcing them together? When have the students reflected enough about their ideas and beliefs about learning, and are ready to put the content in play as the main purpose?

I emphasize how a task should have a clear link between its goal and its design, and potential obstacles from reaching the goal should be weighed as either a relevant learning goal for the task, and else tried omitted.

To me the value of metacognition is not to go all the way as Gunstone (1991a), but to have students know and reflect upon the intended learning outcomes of the task in order for them to understand the learning game.

The idea that students will learn something 'better', if they are given the rules of the 'learning game' and 'playing all cards open' might seem obvious when discussing it in a theoretical context, but when practice emerge, teachers might focus on being well-prepared in relation to the content, and students might find other issues more important, such as getting the job done or convince the teacher of their high knowledge and skills levels.

These ideas are also recognizable from the case studies as well as my own experiences (both as the teacher and the learner). As discussed in section 4.6.2 concerning 'labwork design as obstacle dislodgement', it is perfectly possible for the design of the task to occur before the intentions of the task are laid out, which prevent the 'playing with open cards'.

Another point here is to notice how the ideas of metacognition do not apply to all the learning experiences of life. The learner has to be cognitively capable of understanding the articulation of the purposes. Young children will not benefit from being told how their activities of drawing on paper hold the learning goal of becoming better skilled for future hand-writing. For the case of Gymnasium students their cognitive abilities are developed to an extent where declaration of purposes is making sense. Adey et al. (1989)'s findings from the CASE study indicate the needed cognitive capability is developed not before the age of 12.

Finally, the focus on metacognition has provided analysis methods for studying the data, such as will be discussed section 8.2.1.

8 Empirical investigations of the impacts of declaring intended learning outcomes

In this chapter an empirical investigation of the impact of declaring the purpose(s) of the specific practical work to the students is done. To be able to declare the purposes of the practical work the teachers have to understand the purposes. The previous part (part III) is to be seen as a tool for this.

This chapter contains six sections. The first section 8.1 introduces the empirical cases and reminds the reader of the data extracted about the case teachers in chapter 4.

The following four sections deal with the data from the case studies, which address and answer the research question. Section 8.2 deals with comparing the cases by categorizing the focus students' actions and talk during the labwork activity at the school laboratory in order to quantitatively compare how they spend their time during the labwork. Section 8.3 takes advantage of the detected instances in the previous section to investigate qualitatively how the focus students discuss during the labwork activities. Section 8.4 deals with the interviews with the focus group students of each case in order to detect their understanding of the labwork and its learning purposes. Finally, in section 8.5, the lab reports are analyzed in order to gain insights on how the students solved the written part of the task, and especially which things they have primarily focused on.

In section 8.6, the data results from the previous sections are summarized and a picture of the students' focus and understanding of the labwork purpose are formed. The methods and results are discussed, and the answers to the second research question are drawn forward and discussed.

As seen, the second research question is answered by investigating the cases in a number of different ways. This method and data triangulation values for its ability to make the results stand stronger.

8.1 Introduction to the data

In chapter 4, the pilot investigations and the four cases were presented (Alice, Burt, Charles and Derek). For the case studies, in that chapter focus was sole on the four teachers, and through interviews, and an analysis of their labguides and their labwork introductions their level of declaration was detected. The interview analysis also gave insight into their view of teaching, learning and the school topic of physics.

In this chapter, focus is instead on the students and their response to the labwork tasks. In order to answer the second research question "*What is (if any) the impact on the students of a declaration of the teacher's intended learning outcomes of the specific labwork?*", various ways to investigate the impact on the students are done. Some tools for comparing various labwork activities are needed.

Three types of data from the labwork activities which should be compared have been collected: the video recordings during the labwork activities, the student interviews after the labwork, and the handed-in lab reports.

The video recordings contain both the students' doings and sayings during the labwork. The student interviews were done directly after the labwork, and are run after the interview guide found in appendix B. The reports contain the students' reporting of the labwork along with (for the most cases) the teacher's corrections.

The question is what to look for in the videos, the interviews and reports, in order to detect the impact on the students of the teacher's declaration (high or low level). A difference is looked for, but what the difference is could not be determined prior to looking at the data. So a number of tools for comparing various labwork activities are needed to shed light on the possible differences, whose relevance (if any found) thereafter can be discusses.

In the following four sections, these tools and the respective data are presented and analyzed. The students' actions and sayings are analyzed both quantitatively and qualitatively, and the student interviews and student reports are analyzed in order to shed light on their understanding and taking in of the teachers' intentions (with different levels of declaration).

In chapter 4, four case teachers were followed: Alice, Burt, Charles and Derek.

Though Charles' two labwork activities were intended as a comparative case study, a number of factors demands that this data is substracted from the further analysis. Firstly, as shown in chapter 4, Charles' understanding and prosecution of the intended purpose of the labwork were very poor. Secondly, since both labwork activities were presented and conducted at the same time (half of the class did the halftime experiment and the other half did the halfwidth experiment within the same module), the research design of comparing two similar labwork activities with very different levels of declaration was not executed. Thirdly, the audio of the labwork was very poor, since the students of the focus group were working very close to other groups, making the work of distinguishing the focus group sayings from the other groups very difficult. Fourthly, it was not possible to interview the students after the labwork. And finally, the students of the focus group chose to not hand in one of the lab reports.

So in the following, I will focus on Alice, Burt and Derek and their students. That leaves six labwork activities to be investigated:

Teacher	*Students*	*Labwork*	*Duration*
Alice	Abraham, Abby	Equation of state	2×90 min.
Alice	Anita, Annie	Equation of state	2×90 min.
Burt	Brianna, Bridget, Brit	Conservation of E_{mec}	45 min.
Burt	Bobbi, Bonnie, Bob	Conservation of E_{mec}	45 min.
Derek	Dana, Daisy, David	Halftime	90 min.
Derek	Dana, Daisy, David	Halfwidth	90 min.

All student groups were chosen by the teachers. The choice was not based on their skills in physics and physics labwork activities, but was based on their talkativeness, since for the case of very quiet students no knowledge of their thoughts and reflections could be detected during the labwork activity itself. Also the student groups were chosen so it would be reasonable to expect them to hand in their lab reports on time. This often ended out by overlapping with the students with particular skills and interests in physics. Apparently this also affected the gender composition, which was not a deliberate choice[1]. No access to the students' physics grades was granted, neither before nor after the observations. For the cases of Alice's students and Derek's students, the teacher formed the groups, and for the case of Burt the students were already in preformed groups. For all cases, the students were well acquainted with each other, since they have been in the same class for almost all their lessons for the last couple of years.

Knowledge of the labwork design, setup, apparatus etc. can be extracted from the labguides, such as displayed in appendix D and discussed in section 4.4.

To refresh the reader's memory about the teachers' intended learning outcome of the labwork activities, these are shortly reviewed.

Alice explains her intended learning outcomes of the task very clearly, both during the interview, in the labguide and during her labwork introduction. She focuses on three learning goals of her labwork concerning the equation of state, namely *control of variables*, *graphical data handling* and *familiarization of the equation of state*.

[1] The gender composition is 3 male and 10 female students.

Burt perceives his learning goals of his mechanical energy labwork very different from Alice's. Labwork activities for him are primarily a tool for varying his teaching, and therefore his intentions are that the students like the labwork, are being able to do the labwork, and are seeing the theoretical concepts in a new light. He does not clearly articulate these goals in either the labguide or his introduction, as these goals are of a general kind and therefore the same for all labwork activities his students are doing.

Derek is given the task of presenting two similar labwork activities (halftime and halfwidth) in very different ways. The first labwork about the halftime is presented with no declaration of his intended learning outcomes, whereas the halfwidth labwork is presented with a clear learning goal related to systematic and random uncertainties, both in the labguide and during the labwork introduction.

In the following the different types of data are investigated in order to detect the students' reaction to the different levels of declaration. For the case of Alice and the halfwidth labwork by Derek it is obvious to look for the students' reactions and taking in of the declared learning purpose of the labwork activity. For the case of Burt and Derek's halftime labwork, where the intended learning outcomes were not declared, instead the analysis has to be based on other principles. Therefore the two labguides are investigated in the same way as the typical labwork activities in the Danish Gymnasium (see section 6.4) in order to find potential learning outcomes for the labwork within the sub-skills of the procedural domain. Thereafter the different sources of data (transcripts, student interviews, lab reports) are analyzed in this light.

8.1.1 Analysis of Burt's mechanical energy labguide

The official aim of the labwork is to investigate the transformation between potential and kinetic energy in a motion on an air track.

As for the sub-categories of the procedural skills (see appendix E.2), for those associated with design, the labwork might serve the purpose of *variable identification*, since the students need to recognize the dependent variable of the pass time Δt, which is an indirect measurement of the velocity, and therefore the kinetic energy. The independent variable and the controlled variables change in the same way as for Alice's ideal gas experiment, since the independent variable could be either the travel distance s, the mass of the cart m_1, the mass of the pull weight m_2 or the length of the flag Δs. For each experiment either of the possible independent variables could be chosen, which causes a demand of the others to be controlled. Therefore obviously also the *fair test* ideas could be perceived as the learning purpose of the labwork activity. The labwork is though different from Alice's, since the aim is not to investigate how the change in mechanical energy ΔE_{mec} is a function of the independent variables, since by theory $\Delta E_{mec} = 0$. Therefore investigating how ΔE_{mec} varies with the independent variables will tell the students where the labwork results differ from theory, which in itself also is interesting, but a somewhat different thing. *Sample size* is not addressed, especially since the labguide does to emphasize any quantitative discussions of the range where the data follow the theory of a zero change in the mechanical energy, but only seeks to show how the mechanical energy is somehow conserved. *Variable types* is quite relevant due to the significance of derived variables (the measure of the pass period is in itself not interesting, it is what it says about the speed, kinetic energy and thereby mechanical energy, which is interesting).

For those associated with measurements, *relative scale* is taken care of by the choices of flags, cart weights and pull weights. As discussed above, *range and intervals* is not relevant, since the data range of following the theory is not to be investigated quantitatively. *Choice of instrument* could be discussed, especially in relation to sources of errors. *Repeatability* is discussed, since the data are to be done repeatedly. Somehow the labguide though indicate it to a way to get around potential problems with the counter, and not so much a discussion of repeatability of natural phenomena. *Accuracy* and *uncertainties* are not discussed in the labguide.

For the case of those associated with the data handling, *tables* is of course relevant, but the most of the work is done in the pre-printed table in the labguide. *Graph type* is obviously not addressed. *Patterns* could be discussed in comparing the data, but it is not directly asked for. *Multivariate data* could, as was the case of *fair test*, be relevant for the labwork, but the labwork could easily be done without it. *Units* is an issue, though the conversion is fairly simple. *Equation translation* is not relevant.

For those associated with evaluation, *uncertainties and errors* is addressed, when the students are asked to comment and possibly explain any large deviations. *Reliability* is addressed when the students are asked to give a general evaluation or conclusion to the labwork. *Validity* is not addressed.

As the labwork leads on to a report, the communication skills are included. Here the students are given a structure for the lab report directly in the labguide, so they are not to consider which information is relevant to place in the report.

8.1.2 Analysis of Derek's halftime labguide

The official aim of the labwork is according to the labguide to determine the intensity of the background radiation as well as determining the halftime of $Ba - 137^*$.

In relation to those sub-skills of the procedural domain associated with design *variable identification* plays a special role, since the independent variable is time, which most be perceived by the students as different than an independent variable which they change 'themselves', like placing additional lead plates for the halfwidth experiment. *Fair test* issues are not discussed besides the ideas of the background radiation. *Sample size* and *variable types* are not discussed, though the latter is interesting, since the measured quantity is discrete and measured on a basis of an interval, serving a different role than what the students are most familiar with.

For those associated with measurements *relative scale* could be addressed in relation to the distance between the GM-tube and the substrate. *Range and intervals* could be important in the discussion of how long to keep measuring, but this is pre-determined by the labguide. *Choice of instrument* again could play a role in discussion accuracy, but is not taken up. *Repeatability* is addressed for the background measurement, but it is up to the students how far they will take this information. *Accuracy* and especially *uncertainties* could be very relevant for the labwork, but are not addressed.

Associated with data handling, *tables* is relevant, since the students are in need of designing a table for their data, where they e.g. need to subtract the measured background radiation. *Graph type* is special, since the students are not asked to display the data on a semi-logarithmic paper, but instead to make an exponential regression. Still, the students are most likely not addressing the issue of the discrete data when choosing a type of graph. *Patterns* is obviously discussed. *Multivariate data* is not addressed. *Units* might be addressed in order to change between minutes and seconds, as well as operating with the decay constant and its relation to the halftime, but the students could get by without discussing units. *Equation translation* will for sure be addressed.

None of those associated with evaluation (*uncertainties and errors*, *reliability* and *validity*) are directly addressed, though the first will most likely be relevant, since the students are asked to compare their results with a table value.

Finally, communicate skills and reporting is trained when doing the report.

8.2 Quantitative categorization of labwork activities

This section deals with the quantitative analysis of the labwork activities in the school laboratories. This serves as one among several ways to investigate the impact of purpose declaration on the students' work in school laboratories.

Several tools exist for doing quantitative investigations of student activities. These are reviewed, and one is chosen and modified. This tool for categorizing the activities is a further development of the CBAV (Category Based Analysis of Videotapes), especially developed for labwork activities. The original tool and the included additions are presented, and thereafter follow the data and the results of implementing the tool.

8.2.1 Review of categorization tools

In the field of science and mathematics education research, one of the most classic categorization tool is the one developed by Schoenfeld (1985) for mathematical problem solving at university level. He identifies six types of episodes: *reading*, *analysis*, *exploration*, *planning*, *implementation*, and *verification*, where each of these episode types can include decisions guiding the problem solving process. Schoenfeld's findings are that novice problem solvers spend most time on implementing unproductive ideas and too little time on episodes of *planning* and *analysis*, in other words try out all possible strategies instead of spending time on choosing the better one. Kung and Linder (2007) relate this to the concept of *metacognition*, interpreting Schoenfeld's findings as students spend insufficient time on metacognitive episodes.

The detected episode types of Schoenfeld (1985) were further developed by Artzt and Armour-Thomas (1992), adding *understanding the problem* and *watching and listening*. Each of the now eight episode types were characterized as either cognitive or metacognitive (or neither), again emphasizing the relation between the categorization protocols and metacognition. Also Goos et al. (2002) make use of the categorization protocol by Schoenfeld, including the categories of *new idea* and *assessment*, each designated as metacognitive acts.

Moving away from problem solving in mathematics, Kung and Linder (2007) make use of these categorization protocols and their link to metacognition to develop a categorization scheme for video recordings of physics laboratory work at university level. Having tries out the three above mentioned protocols on the labwork situation, they choose to operate with a three-fold categorization scheme: *off-task mode*, *logistical mode* and *sense-making mode*, where the latter is directly linked to metacognition. The off-task mode is self-explanatory, whereas the logistical mode they explain as "[A]ctivities that must be accomplished through the course of the laboratory, but that do not involve the students explicitly puzzling through or discussing an issue." (Kung and Linder (2007), p. 46). The sense-making mode is where the students are discussing physics formulas or concepts, the design of the experiment, the data, the aim of the labwork task, etc.

As indicated by Kung and Linder, their categorization protocol is not easily used, and reliability issues are of a great concern, since the issues of determining whether a statement is belonging to the logistical or sense-making mode is often difficult, wherefore turning towards yet another categorization protocol for video footage of labwork activities.

8.2.2 CBAV (method for analysing student activity)

To compare the labwork activities as recorded on the video footage, the CBAV tool was found, tested, modified, and implemented.

The Category Based Analysis of Videotapes (CBAV) developed by and described in Niedderer et al. (2002) is a tool for categorizing video recordings of labwork activities on behalf of both the *doing* (the action) in the laboratory and the *saying* (verbalized knowledge) taking place during the labwork activity.

The tool is developed for understanding and comparing labwork activities across countries and different teaching/learning cultures, asking questions like how much time during labwork is devoted to work with different contexts and resources, how much time during labwork is devoted to the verbalization of different kinds of knowledge and which of the contexts are more or less effective in the sense that they promote students' talk about physics during labwork? (Niedderer et al. 2002, p. 35). This leads to answering questions about the link between theory and practice in different labwork contexts (Niedderer et al. 2002, p. 31).

One of the forces of the CBAV method is - the authors state - the ability for analyzing a lot of video recordings in a fairly short time. The results are not to stand alone, though. The method should be complementary, they state, to a more through qualitative interpretative analysis of the learning processes based on e.g. transcripts. Also it should be notices that this method do not take into account the teacher's intentions of the labwork *prior* to the activity, or the learning outcomes *after* the labwork activity, but only investigate the actual activity and verbalizations *during* the labwork.

Earlier studies, they state, have shown how teachers perceive labwork activities as a possibility for students to learn to link theory with practice, to learn experimental skills and to get to know the methods of scientific thinking (Welzel et al. 1998). On the other hand students seem to emphasize following the instructions, getting the job done and finding the right answers, leading to a mismatch between goals, behaviour and learning outcomes (Lunetta 1998). Niedderer et al. emphasize the goal of labwork during the activity to be verbalization of knowledge, and build their analysis tool on this. They place special emphasis on the linking theory to practice in the verbalization during the labwork activities, giving rise to the category of 'technical and physical knowledge'.

The CBAV operates on two levels: CBAV categories of labwork context and the CBAV categories of verbalized knowledge. In other words, what the students do and what the students say. In the former category they operate with nine categories (other, interaction with third person, labguide, manipulation of apparatus, measurement, calculation, computer-measurement, computer model building, and computer model use) and in the latter with four (physics knowledge, technical knowledge, technical and physics knowledge, and mathematical knowledge). These are described in table 8.1 and 8.2.

Table 8.1 CBAV categories of labwork context, taken from Niedderer et al. (2002, p. 36).

Category		*Description*	*Examples*
Other	O	Activities not related to the lab.	Talking about last nights' TV.
Interaction with third person	3P	A third person can be the teacher, the tutor, other students, or similar.	Tutor helps to solve a problem and talks to the students.
Labguide	LG	Using the labguide.	. . . to plan what to do.
Manipulation of apparatus	MA	Using the apparatus and devices. Carrying out experimental set up or preparing a measurement.	Building up an electrical circuit; taking a test-measurement; having a problem with the apparatus.
Measurement	ME	Using the apparatus to gather data and writing them down. Resources used are apparatus *and* paper/pencil.	Taking the pendulum's amplitude and writing the value down.
Calculation	CL	Using a (pocket) calculator or a special software like Excel for this purpose or doing a direct calculation with paper-and-pencil.	Calculating a physics quantity from the measurement data.
Computer-measurement	CME	Replacing category ME in the case of computer-based measurements in labwork (MBL).	Reading the amplitude from the graph on the computer screen.
Computer model building	CMB	Using a modeling software (e.g. STELLA) to created a model structure or make changes or add new relations.	Building a model of an oscillating spring and incorporating a frictional force into this a model.
Computer model use	CMU	Running a simulation when a model (STELLA) is ready and only parameters in the model are changed.	To predict measurement values by the model (simulation of experiment).

The category scheme for the labwork context seems to be rather self-explanatory, and Niedderer et al. also indicate the relative easiness of categorizing the students' actions during labwork activities. The category scheme of the verbalized knowledge is on the other hand much more complex. To state the importance of the verbalized knowledge is not only a mere trick to prevent the need for 'guessing' what the students are thinking, when they are doing or saying particular things. It is also based on the learning hypotheses that explicit verbalization of particular knowledge, e.g. knowledge related to the

Table 8.2 CBAV categories of verbalized knowledge, taken from Niedderer et al. (2002, p. 36).

Category		*Description*	*Examples*
Physics knowledge	KP	Students use physics knowledge, e.g. using words referring to physics.	Talking about how to determine the phase from an oscillation diagram.
Technical knowledge	KT	Students use knowledge more related to technical apparatus. Often related to the handling of apparatus.	Talking about how to operate an oscilloscope; adjusting the interface software.
Technical and physics knowledge	KTP	Student use physics knowledge and technical knowledge together	Talking about how to carry out a measurement for a certain physics quantity.
Mathematical knowledge	KM	Students use formulas in their statements or other mathematical knowledge	Describing the mathematical properties of a measured curve.

linking of theory and practice, is an important step towards actually learning it. Based on this learning hypotheses they develop the categories of physical knowledge (KP) and technical knowledge (KT), where the former involved the verbalization of physics concepts, related to the world of theory and model, and the latter involves verbalization of apparatus and material objects, dealing with the world of objects and events. A third category is then needed, when the students verbalize relations between the world of theory/model and the world of objects/events. This is named technical and physical knowledge (KTP). Finally when the students make use and discuss mathematical knowledge it is categorized in the mathematical knowledge category (KM).

Within this way of categorizing labwork activities, it is important to notice the emphasis of time. The categorization is in practice done by seeing through e.g. 30 seconds of the video recording and thereafter placing the students' doing and saying within the described categories. An excerpt of a possible CBAV scheme can be found in table 8.3. As the authors state: "Niedderer et al. (2002, p. 35)"We quantify 'talking about physics' by the 'time of talking'..., not going into detail of the 'quality' of the verbalized knowledge, but instead lead the important variable be the time spend on talking. This leads them to defining variables like 'density of knowledge verbalized in a special lab context', which they see as an indicator of the effectiveness of a special lab context in promoting knowledge verbalization. This variable can be used to answer questions like to which extent does the measuring process of labwork promote verbalization of physical knowledge?

As given by the book review by Hodson (2005) the CBAV tool can obviously be critiqued on a number of instances:

Table 8.3 Excerpt of a CBAV scheme.

t	*Context*										*Knowledge*				*Comments*
Min	O	3P	LG	PP	MA	ME	CL	CME	CMB	CMU	KP	KT	KTP	KM	
0.0			1								1				Component telescope
0.5			1												
1.0			1								1	1			Loading software

> I was left wondering just what such an elaborate system could tell us about the quality of the talk, who does the talking, how it is received by others and what responses it generates. I was left wondering, too, about what CBAV could tell us about all the other categories of talk that do so much to generate the appropriate affective and social climate in which productive practical work takes place. The answer, of course, is nothing at all. What the authors do report as research findings positively pulsates with banality: manipulating apparatus generates more talk about technical matter than about physics concepts; interacting with a tutor generates more talk than manipulating apparatus.
>
> (Hodson (2005), p171)

This critique runs on two levels: Hodson lists the many important features of labwork activity which the tool neglects, and he states how banal the results emerging from this analysis are.

My use of CBAV

In line of Hodson's first point of critique it is important to underline that the results of the application of the CBAV cannot stand alone. For the case of this work, the issues of the quality of the verbalization of the knowledge play a significant role, and therefore the transcripts have to be investigated afterwards. This tool is though found to possibly be valuable in comparing different labwork activities concerning different topics and/or students to find to which extent the labwork activities share similarities on both the action and the verbalization of knowledge.

As opposed to Niedderer et al. (2002), I do not place particular (only) emphasis on the intended learning outcome of linking theory and practice. Instead I wished to investigate which affects the teacher's verbalization of intended learning outcome(s) has on students sayings (and to some extent actions) during labwork along with what can be detected of their learning after the labwork activity as it is to be found in the handed in reports. During my observations I got a feeling that something was remarkably different in the labwork activities, where the intended learning outcomes were explicitly articulated, and using this tool of CBAV I wish to investigate the nature and degree of these observed differences.

Having done a first categorization of the observed labwork activities using the CBAV scheme, it became apparent that somewhat different categories than those presented in the article of Niedderer et al. (2002) was needed.

For the case of the categories of action, first of all it was not found important to disassociate between those cases where the labwork data collection was done by use of a computer software or by analogue data collecting. Also none of the labwork activities included modeling software, for which reason the categories concerning this was omitted. Instead two additional categories were included: one concerning student activity related to the labwork, but not included in the other categories. This could be moving between labwork apparatus, clarifying which activity to do next etc. This was named other lab (OL). Second a category was included when the students talked specifically to the teacher, named interaction with the teacher (3T). Therefore the former category of interaction with third person (3P) now only includes interactions with people not being in the group or being the teacher, e.g. other students of the class or me. The modified scheme of labwork content can be found in table 8.4.

Also additional categories for the sayings were included. It was found important what kind of talking the students were doing when they were not actually expressing knowledge. Therefore three additional categories were included. A category for silence (SI) was included. Occasionally the students do not say anything or almost anything to each other. Also a category for talking about things not related to the labwork (OT) was found useful. Finally a category for those instances where the students are talking, but not expressing knowledge was needed. This was named labtalk (LT). The modified scheme for the verbalized knowledge can be found at table 8.5.

8.2.3 Examples of categorizations

In this section examples of each of the verbalization categories will be given to outline which understanding of the categories is chosen. First some 'clear-cut' examples are given, and thereafter some of the more fluffy examples are given to explain how the same transcripts can give rise to different categorizations.

Each of the examples are taken from the same laboratory task of the case teacher Alice (Group 2 with Anita and Annie), since the data of this labwork has marks in each of the categories.

Starting out with the verbalizations of the students, 30 second excerpts are given for each of the categories to give an insight into the categorization choices. Each excerpt is chosen to be the most exemplary for the categorizations. A lot of the transcripts are muddier, and therefore more difficult to categorize.

Table 8.4 The modified CBAV categories of labwork context.

Category		*Description*	*Examples*
Other	O	Activities not related to the lab.	Checking videos on YouTube.
Other labwork	OL	Activities related to the lab not included in the other categories	Moving between labwork setups.
Interaction with teacher	3T	Interaction with the teacher	Teacher helps to solve a problem and talks to the students.
Interaction with third person	3P	A third person can be the other students, or similar.	Other students help out with a problem or talk to the students.
Labguide	LG	Using the labguide.	. . . to plan what to do.
Paper and pencil	PP	Using paper and pencil or computer to note down things	Making measuring schemes
Manipulation of apparatus	MA	Using the apparatus and devices. Carrying out experimental set up or preparing a measurement.	Building up an electrical circuit; taking a test-measurement; having a problem with the apparatus.
Measurement	ME	Using the apparatus to gather data and writing them down. Resources used are apparatus *and* paper/pencil.	Taking the pendulum's amplitude and writing the value down.
Calculation	CL	Using a (pocket) calculator or a special software like Excel for this purpose or doing a direct calculation with paper-and-pencil.	Calculating a physics quantity from the measurement data.

SI - silence

This categorization is given a half of a minute period if nothing or almost nothing is said. A lot of things could occur at the same time in the categories describing the action.

As an example of a 30 second period which was categorized as SI is when Anita and Annie have discussed how to store the data from last time, which are currently on a computer without internet access. They have borrowed a floppy disc from Alice. When the data is saved they wish to pursue from task 1 to task 2.

1067 **Anita** [Anita looks at a floppy disk.][2]
1068 **Annie** [looks at the labguide]

[2] The line numbers refer to the transcript report.

Table 8.5 Modified CBAV categories of verbalization.

Category		*Description*	*Examples*
Silence	SI	Students are silent	...
Talking not related to labwork	OT	Talking about last night's tv.	
Laboratory talk without expressing knowledge	LT	Students are talking about laboratory relevant issues without expressing knowledge	Reading out data findings.
Physics knowledge	KP	Students use physics knowledge, e.g. using words referring to physics.	Talking about how to determine the phase from an oscillation diagram.
Technical knowledge	KT	Students use knowledge more related to technical apparatus. Often related to the handling of apparatus.	Talking about how to operate an oscilloscope; adjusting the interface software.
Technical and physics knowledge	KTP	Student use physics knowledge and technical knowledge together	Talking about how to carry out a measurement for a certain physics quantity.
Mathematical knowledge	KM	Students use formulas in their statements or other mathematical knowledge	Describing the mathematical properties of a measured curve.

As seen from the transcript, absolutely nothing is said, and is therefore categorized as SI. But at the same time they are working with the labwork task.

OT - other talk than labwork related

This categorization is given a half of a minute period if the things discussed are not related to the labwork task. Annie and Anita ask about why they are video recorded.

498 **Annie** So no one but you will see this?
499 **LBJ** Absolutely no one but me is going to see this.
500 **Annie** Well, okay, sounds lovely. When are you going to interview us?
501 **LBJ** If you have time after class, just some minutes, or else next Monday.

This discussion has nothing to do with the labwork activity, and is therefore categorized as OT.

LT - labtalk not expressing knowledge

This categorization is given periods where the things discussed are related to the labwork activity, but no knowledge within the other categories is expressed at the time. Anita and Annie measure the pressure as a function of the volume (task 1). The numbers they read out are the chosen volumes, which is to be typed in to the software program. 'Keep' is the name of the button to press when the pressure should be measured.

Annie Like that, 12.
Anita 12, 'keep', 12.
Annie 15.
Anita 'Keep', 15.
Annie Then it is 'keep'.
Anita What do we have now?
Annie 18.
Anita Yes.

This is a typical transcript for the category of LT. They are not talking about anything which is not related to the labwork activity, but are at the same time not expressing any knowledge or asking questions related to knowledge about either mathematics, physics, the experiment, or its connection.

Another typical example is those, where the group members read out excerpts from the labguide:

Anita [Reads from the labguide] 'A source of error could be a small volume of gas trapped in the pressure meter itself. If the graph does not fit try adding e.g. 1 millilitre to the volume in the fit equation (Ask if you are not aware of how this is done in the software)'.
Annie [Laughs, is not able to understand it]

KT - verbalized technical knowledge

This categorization is given to periods where the discussion is expressing knowledge or relevant questions related to the functionality of the labwork apparatus. Anita and Annie are determining the barometric pressure by measuring the mercury level on a wall-hanging barometer.

Annie It is precisely 160 [reads out the top mercury level]
Anita 760. And we had to measure the difference, wasn't it what she said?
Annie Yes, and it is on 0. It is on 0.4 or something.
Anita 3 and a half. Isn't it on four. Then it has to be seven hundred…
Annie 56. Yes. And how much is that then?
Anita 756 [notes down].
Annie Then we just need it in hecto Pascal.
Anita 756 millimetre. Do we have to do it now? Does it matter if we do it later, shouldn't we just move on?
Annie Yes, we wait with that.

Here they are sole talking about how to operate the equipment, in this case the software program. They seem to have some kind of knowledge of how to operate it, and if they do not, they are able to articulate their insecurities.

KP - verbalized physics knowledge

This categorization is given to those periods where some knowledge of physics is given, such as using terms of physics etc.

This example is given while Anita and Annie are taking back the units to SI-units of task 3 (volume of air bubble trapped in paraffin wax as a function of temperature):

Anita V is equal to Rn divided with p times T. Like that. Good. That means n is proportional to [mumbles to herself]. Eh. Okay. So R - it measures in the same [unit]? In Pascal times cubic metres divided with mole times Kelvin?

Anita Yes.

Here the students are talking about the equation for the ideal gas law and the units of its components, and thereby expressing physics knowledge.

KTP - verbalized knowledge combining physics and technical knowledge

This category is given to those periods where knowledge of the connection between the experiment and their physical knowledge is found.

This example is where Anita and Annie have done the measurements for the first task of the pressure versus the volume. Now they discuss which function they are to fit the data to. This verbalization is given both the category of KTP and KM.

Anita You think it is proportional then?

Annie Yes [in doubt].

Anita We should be able to see it by that formula. Eh.

Annie It is p times V is equal to n times R times T.

Anita Eh. [Picks up the labguide.] What is the connection between V eh?

Annie p and V?

Anita p and V. Well, so p is equal to nRT divided with V.

Annie Yes, you can also say, that if you want these three to be constant, then. . . .

Anita But you can say they are reciprocal, when they multiplied with each other gives a number, right?

Here they are discussing what is the connection between the measured quantities and the expected result.

KM - knowledge of mathematics

This category is given to verbalizations where the students express knowledge of mathematics, which is interpreted e.g. as when they discuss possible mathematical operations of equations, either taken from the theory or from the data fit equations.

In this excerpt the students are working with translating the units of the data of task three, which they did at the previous labwork session.

Anita And n that is given in mole, and it has to divided with Pascal. And then Pascal is deleted with Pascal.
Annie What we measured in millilitre, right?
Anita Then it is just cubic metres pr. Kelvin. And that you can just change to millilitre.
Annie Yes. That is [mumbling] millilitre, so it has to be [mumbling] over Kelvin.

In this transcript they are not really talking to each other, but are both trying to calculate the same task. Therefore it does not really make sense what they are saying when relating it to the other. But they are both expressing knowledge of how to do mathematical operations on the equation in play.

8.2.4 Data extracted by use of CBAV

Having now described the tool for quantitatively analyse the students' labwork activities, the results of categorizing the data are displayed here.

Each of the observed labwork activities was fully transcribed and time-coded. Looking through the video again, the actions categories were implemented, and when reading through the transcripts the sayings were categorized. Short comments were added to give an overview of the progression of the labwork tasks. An example of the results of this work is seen at table 8.6, and the other five can be found in appendix F.2.

As seen, the x-axis forms a time-line. Each 30 seconds are coded in relation to the students' actions and saying, and are displayed in the diagram. The comments are added to the time-line, so to provide an overview of the progression of the labwork. As seen, one interval of 30 seconds can have marks in several of the categories of action or sayings at the same time (since the students could both be setting up equipment and looking in the labguide, or addressing both mathematical and physical knowledge at the same time).

Interpretations of CBAV diagram

In table 8.6 (and the similar tables of appendix F.2 an intense amount of data is compressed too very little space, and therefore the information is probably quite overwhelming.

For the labwork of Alice's first group displayed in table 8.6, the students are working over two days adding up to around 170 minutes. Within this period of time, the students perform four experiments (experiment 1 measuring p as a function of V, experiment 2 measuring p as a function of n, experiment 0 determining the weight of atmospheric air, and experiment 3 measuring V as a function of T). For experiment 1 and 2 time is spend during the labwork to handle the data and perform regression on the data. Also during the labwork, Alice makes the students do two related calculation tasks. The first is based on the results to extract the probable additional volume in the pressure meter, and the second is about manipulating the units in order to extract the value of the constant variable on the basis of a given value of the gas constant.

In interpreting the diagram, to start from the bottom of the ‘y-axis’ the students spend very little time on not directly working with the labwork (O and OL), and these are situations where the students are in transition waiting for the teacher to allow them to move on to other tasks. For the case of the talk with the teacher (3T), this is spread out over the entire labwork, changing between very short comments and longer discussions.

Table 8.6 Diagram of the categorization of the actions and talking during Alice's first group, when working on the labwork concerning the equation of state.

The labguide (LG) is not surprisingly most used when setting up equipment, but are also occasionally shortly consulted when handling data. When consulting the labguide, typically the students express technical knowledge (KT), but almost equally often sayings expressing the link between technical and physical knowledge (KTP) concur with consulting the labguide.

When manipulating apparatus (MA), both technical and technical/physical knowledge is expressed. When doing the measurements (ME), to a lesser extent the students discuss technical issues, but more often operate with the KTP category. When calculating (CL) the mathematical knowledge comes in play, though the other types of knowledge do occasionally also happen during calculations.

The students are mostly silence (SI) for a longer period of time when doing long measurements (experiment 3). As was also the case of doing things not related to the labwork activities, very rarely the students discuss issues with no relevance to the labwork.

When having labwork not expressing knowledge (LT), this most often occur when the students are setting up and doing measurements.

Validity and reliability of the CBAV tool

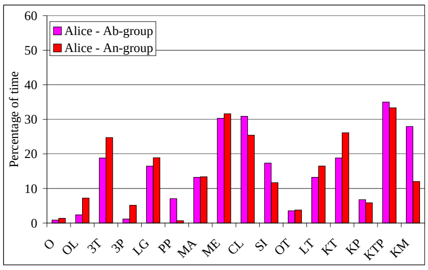
Before discussing the quantitative results of comparing the different cases, the validity of the tool is investigated in relation to the collected data.

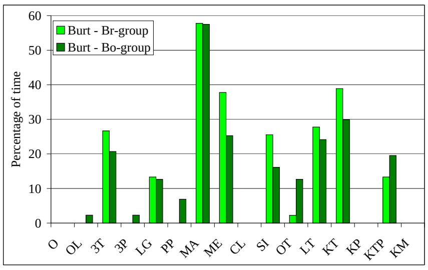
All of the issues found by going through tables like table 8.6 are of course interesting in relation to understanding the nature of students' work with labwork activities (which was the use of the tool by its developers (Niedderer et al. 2002)), but the real value of the tool for this study is its ability to compare different labwork activities with different teachers and different students and different topics in relation to the declaration level. This tool can compare how much time is spend on the different categories. To be able to extract any information about the use of the different categories as a function of the declaration level, a measure of the trustworthiness of the tool is relevant.

When comparing two equal labwork activities with different students - but with the same level of declaration - a measure of the validity and reliability of the tool for comparison reasons can be extracted. For the first two cases (Alice and Burt), two different student groups for each teacher did the same labwork with the same conditions (like labguide, introduction, previous taught knowledge of the task, etc.). Therefore it is relevant to compare these.

As seen from figure 8.1, especially for the action categories there are a close resemblance between the two groups, indicating that the nature of the labwork and its presentation dictates how the time is spend during the labwork. For the case of what the students talk about, it is seen how especially Alice's two

Figure 8.1 Comparison of Alice's and Burt's two groups, respectively. As seen the data of the actions and sayings add up to more than 100 percent, since several categories can be marked simultaneously.





groups are very similar in their pattern of talking, where only the KM category (expression of mathematical knowledge) differ a lot. For the case of Burt's two groups, they differ significantly on the talking categories not expressing knowledge, but for those categories expressing knowledge, they are very similar. Unexpectedly the ME category for Burt's two groups differ significantly.

But generally, the tool indicate similar patterns for the same labwork independent of the students doing the labwork activities - though with minor differences for a few of the categories.

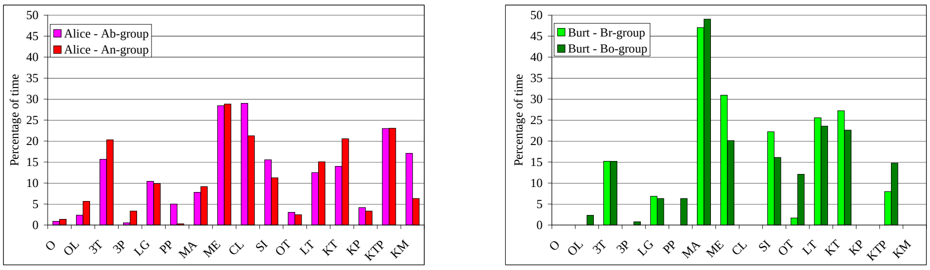
One could argue for another way of displaying the bar charts, where if in one interval two categories were marked, then the markings should only be given half the value (and etcetera for a larger number of co-codings). In this way the actions and sayings categories will each add up to 100 percent. Such bar charts can be found in figure 8.2.

As seen, the conclusion for this way of displaying the results is very similar; that is generally the same labwork show the same type of codings independent of the students doing the labwork (with minor deviations in a few of the categories).

By use of these two ways of displaying the data, the tool seems trustworthy.

Yet another discussion in relation to this is the trustworthiness of the coding itself; is the coding reproducible? Niedderer et al. (2002) have some comments in relation to this, and when reading about other coding protocols such as those described in section 7.3 great concerns are given to these issues. To investigate the trustworthiness of the coding tools, typically two tests are done. Firstly, several coders code the same video footage twice, and the results are compared, and the number of identical codes is detected. The same test is done for two

Figure 8.2 Comparison of Alice's and Burt's two groups, respectively. As seen the data of the actions and sayings add up to 100 percent, since when several categories are marked simultaneously, they are given the respective fractional value.



different coders coding the same data set. The tool is labelled as reliable if the number of equal codes adds up to more than 80%. For the CBAV Niedderer et al. (2002) report for the case of the talking for different coders the coding were quite in-consistent, whereas for individual coders the issues were not severe. The action codes are seen to be reliable.

When not having access to research assistants to double-code my data, it was tried to limit the uncertainties by repeating the coding a number of times. The data was looked through again and again until no codes were changed. After having collected all data and coded them, the data was gone through once again to detect if any inconsistencies between the uses of the coding categories in the six cases were detected. Again this was repeated until no codings were changed.

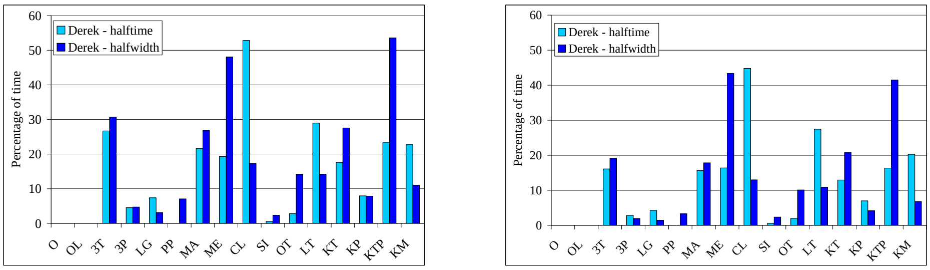
First after this iterative process the categories were compared for the different groups as well as the different cases. Based upon the above discussion of comparing similar cases (the iteration proces to prevent inconsistencies in the coding), and the fact that the coding was finished before the results were compared make the coding data stand fairly strong. Still coding is based on subjective decisions, and therefore a certain uncertainty range should be accepted. Based on the data displayed above it was estimated that the uncertainties were in the area of ten percentage points or 15 percent without any further argumentation., wherefore two categorization levels are discussed as equal, if they have same the same values within these error bars.

Comparative cases - Derek's CBAV results

Having compared the two cases where different student groups work with the same labwork, now the two different labwork activities (though as similar as possible) of Derek's with the same student group should be compared.

As seen in figure 8.3, the labwork actions for the two labwork activities are not as equal as Alice's and Burt's cases (where the compared labwork activities were the same).

Figure 8.3 Comparison of Derek's group's two labwork activities (halftime and halfwidth). For the left graph, as seen the data of the actions and sayings add up to more than 100 percent, since several categories can be marked simultaneously. For the right graph the data of the actions and sayings add up to 100 percent, since when several categories are marked simultaneously, they are given the respective fractional value.



The categorization levels of the halftime and halfwidth labwork activities are distributed somewhat equally for the O (other), OL (other labwork), 3T (teacher talk), 3P (talk with other than teacher or group), LG (reading labguide), PP (paper and pencil), and MA (manipulating apparatus). But for the case of ME (measurements) and CL (calculations), the time is spend very differently. For the half-time experiment, the time of the actual measurements was confined to around 5 minutes, since after that most of the Barium had radiated to a stable substrate. Though the labwork were repeated, and some time as spend on measuring the background radiation, much less time were spend on doing the actual measurements compared to the half-width experiment, where a severe amount of time were spend on measuring the radiation count with different numbers of lead plates (where each measurements were repeated a number of times), along with similar measurements of the background radiation. In the halftime labwork, the extra time was instead used for calculations and starting on the report writing (primarily the CL category).

One could argue how the time spend on calculations would most likely cause an intense discussion where knowledge is expressed. When looking at the sayings categories, some interesting differences are seen.

For the case of the silence category (SI), the numbers are both low. The other talk category (OT), for the halfwidth labwork the category level is quite higher than for the halftime labwork. During the long time of measuring, the students a spending some minutes of talking about the party last night, which cause this peak. On the other hand, when talking about the labwork activity itself, the students spend more time during the halftime labwork to talk about things not expressing knowledge (LT) than for the halfwidth labwork.

For the knowledge categories, especially the KTP (physical and technical knowledge) and KM (mathematical knowledge) are very different. The argument of the enhanced KM-level of the halftime labwork most likely is that the students spend significantly more time on calculation and therefore assess their mathematical knowledge more often.

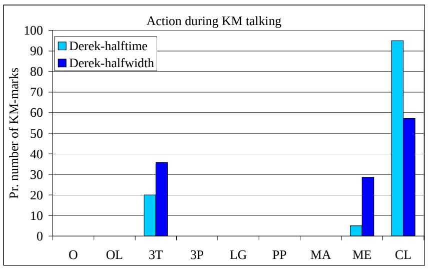
This hypothesis is validated by plotting the action categorizations concurring with marks in the KM category. The results can be found in figure 8.4. For the case of the halftime experiment, by far most of the mathematical knowledge is stated during calculations. Much lower levels are given for the teacher talking (3T) and the measurements (ME) categories. On the other hand for the halfwidth experiment, the mathematical knowledge is more or less equally distributed between calculations and talking with the teacher. On that basis it can be concluded that the enhanced level of mathematical knowledge expressed in the halftime experiment correlate strongly with the higher level of calculation action. Another way of proving this point is by leaving out all the 30 second intervals, which is categorized as having calculation action, see figure 8.6, where it is seen the KM level equals for the two labwork activities.

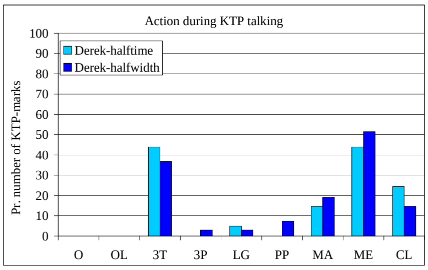
The same investigation is done for the other knowledge category, where the categorization levels are very different for the two labwork activities, namely the KTP (technical and physical knowledge). The results are found in figure 8.5. Here it is seen how the action during KTP-sayings are spread out at the same categories with indications of like categorization levels. That is, when expressing combining technical and physical knowledge, the students are performing similar actions for the two labwork activities. Therefore the previous argument of enhanced KM level of the halftime labwork only being due to relatively more time spend on the CL category cannot be translated to stating that the enhanced KTP of the halfwidth labwork is due to relatively more time spend on the ME category.

So, is the KTP level (technical and physical knowledge) enhanced of the halfwidth experiment compared to the halftime experiment due to a higher declaration level? This question is not easily answered, but it is obvious from the previous discussion and showing of data that it is not only due to a different

Figure 8.4 Comparison of the action categorizations of Derek's group's two labwork activities (halftime and halfwidth) when concurring marks in the KM category. As seen the data of the actions and sayings add up to more than 100 percent, since several action categories can be marked simultaneously.

Figure 8.5 Comparison of the action categorizations of Derek's group's two labwork activities (halftime and halfwidth) when concurring marks in the KTP category. As seen the data of the actions and sayings add up to more than 100 percent, since several action categories can be marked simultaneously.

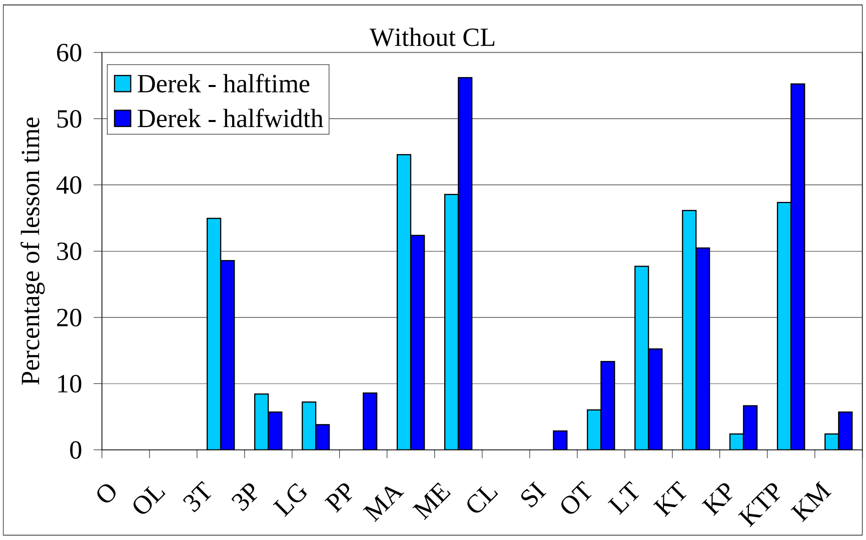




spreading of the action during the labwork. Instead, there most be something fundamentally different between the two labwork activities that cause this enhanced level. Since the students are the same, the teacher is the same, the equipment is more or less the same, the topic is the same, the data handling is more or less the same, the level of difficulty is more or less the same it is pointed to the different levels of declaration of the teacher's intentions with the labwork that cause the found differences. I am aware that a critic could give a number of other arguments for the detected difference, but the nature of the research question demands an answer based on indications more than solid proofs.

One other issue, which is obviously different between the two labwork activities is that during the first labwork of the halftime experiment the students are unfamiliar to the apparatus and are still uncertain of the concepts in play, whereas in the second labwork 3 weeks later the students are much more familiar with the apparatus and the concepts of radioactivity. To argue against this being the major factor for the differences of the KTP level (technical and physical knowledge) the KT (technical knowledge) and the KP (physical knowledge) levels are investigated. As it is seen at figure 8.3 the students spend more time expressing knowledge of (or posing questions about) the apparatus and its functionality (KT) for the second labwork than the first, indicating they still have the need to discuss the technical issues of the labwork. The amount of discussion of the physical concepts (KP) is equal for the two labwork activities, indicating they have the same need of discussing theoretical issues for the two

Figure 8.6 Comparison of Derek's group's two labwork activities (halftime and halfwidth) with the action category of calculation (CL) omitted from the data set. As seen the data of the actions and sayings add up to more than 100 percent, since several categories can be marked simultaneously.



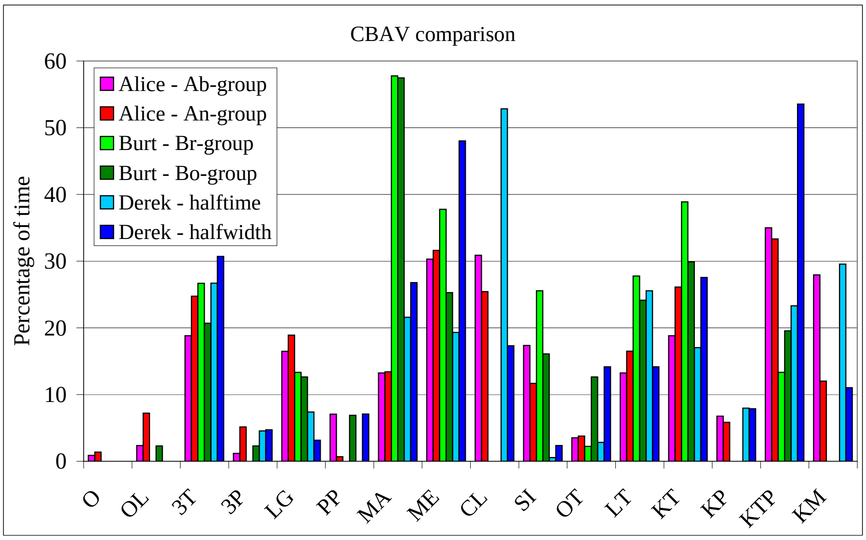
labwork activities.

Comparing all cases

Having now argued for the tool as a way to compare similar or equal labwork activities in relation to detecting relevant differences in the levels of expressed knowledge, now all six labwork activities are compared.

In figure 8.7 the data from all six labwork cases is displayed. As seen for all cases, within the action categories the students spend very little time on performing actions in the other (O) or other labwork (OL) categories. Comparing such different labwork activities it seems the students spend more or less equal amounts of time debating with or consulting their teacher. Each labwork case spends little time discussing with other people than the teacher and their own group members (3P). For the case of addressing the labguide, Alice's groups use

Figure 8.7 Comparison of all six labwork activities. As seen the data of the actions and sayings add up to more than 100 percent, since several categories can be marked simultaneously.



it more than the others, probably since the students are asked to do four experiments with different equipment demanding them to consult the labguide more often (though the labwork itself also take up much longer time). Not too much time is spend for either of the groups in the paper and pencil (PP) category, which is synonymous for doing measuring schemes and the like. For the following three categories (MA, ME and CL), much larger differences are detected (the amount of coding in these categories are also much larger). For the case of measurements, Alice's two groups spend fairly little time setting up, whereas that is the prime activity for Burt's two groups (having severe problems tying the pull weight to the string and finding room for the photo cell). When seeing this, the differences detected when only comparing each teacher's two labwork activities seem fairly small compared to the differences between Alice's, Burt's and Derek's labwork activities. For the case of the measuring category (ME), large differences are detected, where Derek's halfwidth experiment uses almost half the time on measuring, while the halftime experiment spend less than one fifth. The same immense differences are seen when comparing the calculation activities (CL), where Burt's two groups do not do any calculations, and Derek's halftime labwork dedicated more than half the time on calculations.

In case of what is said during the six labwork activities, the variation between them is large. Derek's group obviously is very talkative compared to the other groups, since the silence category (SI) is much less used for them. The data from the OT and LT categories are also very fluctuating. Going to the knowledge categories, also differences are seen.

For the case of the technical knowledge Burt's two groups score highest, but these are also doing the labwork activities with most time spend in the MA category. Concerning the physical knowledge, Burt's groups have no hits in this category, whereas both Alice's and Derek's groups make use of this category with equal coding levels. For the case of the combining technical and physical knowledge category (KTP), Alice's groups score high compared to Burt's groups as well as Derek's halftime experiment. Derek's halfwidth experiment scores the highest. Finally, for the mathematical knowledge category (KM), this is not used for Burt's groups since they spend no time on calculations. Derek's halftime labwork score highest, and the halfwidth lowest (with little calculation time).

Again interpreting high levels in the knowledge categories as desirable - and especially those in the KTP category, correlations between the declaration levels and the knowledge category levels exist. Alice's two groups and the halfwidth labwork by Derek had clear-cut declarations of the intended learning outcome, whereas Burt's two groups and Derek's halftime labwork were not given this information. High levels in the other knowledge categories are explained by enhanced levels in the correlating action categories.

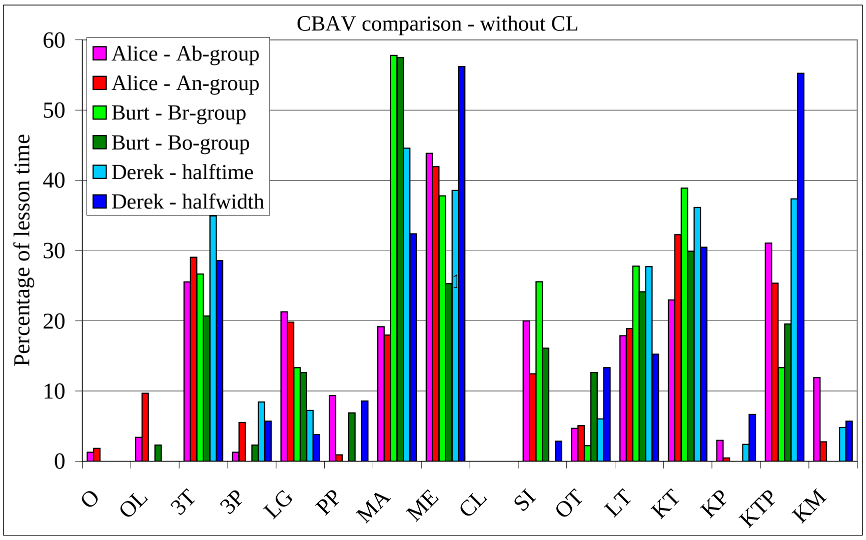
One could again argue the differences are due to the calculation activity level, see figure 8.8. Of course it changes a lot on Derek's halftime labwork and for Alice's two groups, since these are spending a quarter to half of the time on calculations. On the other hand, the results to some extent still hold, when interpreting them as enhanced KTP level correlates with enhanced declaration level (Derek's halftime labwork show a high level of KTP, but it seems difficult to interpret this since half of the labwork time has been omitted).

Comments on the CBAV data

Obviously the work with the coding and the development of the coding schemes was done while developing the answer to the first research question presented in the previous part III. Therefore the knowledge categories need some comments in relation to the answers to the first research question.

As seen from the table connecting labwork types and general labwork purposes (table 6.8), *exercise* labwork activities serve the prime purpose of teaching

Figure 8.8 Comparison of all six labwork activities when omitting the calculation action. As seen the data of the actions and sayings add up to more than 100 percent, since several categories can be marked simultaneously.



students skills from the procedural domain. Secondary purposes are the conceptual domain and the affective domain. I have deliberately not taken up the affective domain in the analysis of the students work with labwork tasks.

As discussed in section 5.4 and exemplified in the work leading on to table 6.11, the procedural skills domain should be understood as much more than being able to follow directions on to how to use equipment. The procedural skills domain operates with a number of sub-skills associated with design, measurement, data handling and evaluation.

The four knowledge categories - though obviously not displayed in the same way as the categories of the procedural skills domain - share a number of relevant parameters. The technical knowledge category (KT) operates with understanding and being able to use equipment, directly related to the sub-skills of e.g. *choice of equipment*. The physics knowledge category (KP) relates to the conceptual domain, but also links to some of the sub-skills of the procedural skills domain, such as *variable identification*. The technical and physical knowledge category (KTP) bares relations to the pretty much all of the procedural sub-skills. Finally, the mathematical knowledge category relates to the skills associated with data handling, where the limit between mathematics and data-handling skills is blurred.

Therefore the categories are relevant, and if the data were to be categories according to the recognized sub-skills of the procedural domain, the number of categories would extend (to an even higher extent than now) to an unreasonable number.

I have participated in a number of conference workshops where quantitative data has been presented. Here the afterwards comments were all related to the precise numbers and quantities and not so much to the underlying data collection, the research hypotheses and the validity and reliability of the data. I intent that these data are looked at in a different way than the quantitative data from the conference workshops. The data results here displayed are only one among several ways of showing a significant impact on the students' way of working with a labwork when understanding the intended learning purpose of the activity. It is not so much if a value is 1.2 or 1.3, but should be seen as a strong indicator of a result to a question that is somewhat impossible to answer.

Having chosen not to use the tool developed by Kung and Linder (2007) for categorizing the student labwork activities (see section 8.2.1), still some comments on how the results would overlap and differ are in place. Kung and Linder (2007) operate with three categories of the students' sayings during the labwork: off-task, logistical and sense-making. The off-task mode easily overlaps with the other talk (OT) category. The logistical mode is understood as the talking needed to perform the labwork, but not to understand, reflect and puzzle with it as a problem to be solved. This has a strong level of overlap with the lab talk (LT) category, and has slight overlaps with the technical knowledge (KT) and the mathematical knowledge (KM), whereas the other knowledge categories (KP and KTP) relate to the sense-making mode, and thereby emphasizing the same categories as important, whether they are named knowledge categories or sense-making mode.

As was also the case of the CBAV developers, I emphasize the KTP-level as an indication of enhanced understanding of the labwork activity in relation to understanding and interpreting it as a physics task, and not sole as a task to make the students be able to operate equipment (KT), learn concepts of physics (KP) or learning mathematics (KM). I have no evidence that enhanced levels of the KTP category provides better learning (whatever that precisely is), but I claim - and hope to have convinced the reader - that it is a reasonable and desirable parameter for better understanding of the task.

This here used tool does not provide any insights into the various students and their personal understanding. One student could be the person behind all knowledge statements. This tool does not distinguish between each group members, and that is yet another reason for not letting these results stand alone.

As is important to notice, this is only a quantitative comparison. This tool does not provide an understanding of the quality of the students' statements. When categorizing a statement of e.g. KTP, it is valued equal if the statement expresses a high level or a low level of understanding. As decided a statement is marked in a given category, both if understanding or knowledge is expressed, but also if doubts or questions are put forward.

Still, if a student poses questions or expresses a lacking understanding, it is valued since this is a step towards understanding (see section 7.1). In the following section, the quality of the sayings is investigated. By use of this much more detailed analysis, it is possible to detect which labwork actions that provide the wished for discussions and reflections.

8.3 Qualitative transcript analysis

Having investigated the students' activities during labwork activities in a quantitative way, indicating severe impact of the declaration on the way the students discuss the labwork both when comparing the two naturalistic cases (Alice and Burt) and the two experimental cases (Derek's halftime and halfwidth), I now turn to a qualitative investigation of the students' sayings during the labwork.

It is possible that a large number of marks in the knowledge categories is not correlating with expressing a high quality of knowledge. Since the categorization scheme does not separate low and high quality statements, the quantitative results can not and should not stand alone.

On the other hand, it is complicated to discuss the quality of a statement, since one can never truly know what the person giving the statement meant with it. Also, there is always the risk when taking statements out of a context that they are misinterpreted either as of higher or lower quality than they display when read into the context. Finally, it is very difficult to choose transcripts as typical for the knowledge expressed during an entire labwork activity.

Therefore it has been chosen to look for transcripts in two ways. First it seem obvious to look for places where the students react to the declared intended learning outcomes in the cases, where this is done. This provides an insight into how the students have understood, accepted and dealt with the declared learning goals the teacher has for the task.

What to look for in the cases where the teacher has not declared a learning goal for the labwork activity? It seems unfair to judge the labwork by looking for statements dealing with the same learning goals as for the cases of a high level of declaration, especially since the labwork task analysis of section 6.4 shows that different labwork activities hold the potentials for teaching different learning goals. Therefore the analysis of the Burt's mechanical energy labguide and Derek's halftime labguide (section 8.1.1 and section 8.1.2) are used to dictate which learning purposes to look for in the transcript. Thereafter the transcripts are again looked through to see if any high quality statements are given not already looked upon.

8.3.1 High level of declaration

The transcripts for the cases with a high level of declaration (Alice's two groups and Derek's halfwidth group) are investigated in order to detect direct responses of the declared purposes. For Alice's two groups (Abraham and Abby, Annie and Anita) it is variable control and graph translation, and for the case of Derek it is uncertainties (systematic and random).

Abraham and Abby

Here follows a few excerpts chosen from a larger pile, where Abraham and Abby address variable control and graphical data treatment.

Variable control

First variable control discussions are displayed, where the students discuss the concept in their own words.

In the following excerpt Abby and Abraham have plotted their data from the first experiment (p versus V) and are discussing which function to fit the data to (according to the ideal gas law there is a reciprocal connection between p and V).

Abraham 'Choose the wanted function type in the roll-down menu.' That has to be, well…

Abby 'A comma B' or what? [one possible function type displayed in the software]

Abraham A 'B times A squared'? What is that one called?

Abby Have we thought about their relation? [the relation between p and V] We ought to be able to calculate it from that one [the ideal gas law]…

Abraham Yes, from…

Abby …this one, right? And if you then **isolate the volume**, then it is …

Abraham We just want the volume **on the other side** [in the equation].

Abby …nRT/p, or is it…?

Abraham No, it is the other way around, because p **is the function value**. So, you just have to write it the other way around, just swap V and p.

Abby Then it is, then it just inverse proportionality, right?

Here the students discuss the role of the different variables types in play. First the students guess the connection between the pressure and the volume from the patterns the measurements display on the graph. Abby puts forward how the connection can be assessed by the ideal gas law, and Abraham clearly understands that the pressure is the dependent variable, and therefore should be isolated in the ideal gas law, so to make the formula fit the graph. Abby has it upside down and wants to isolate the volume, but when having it cleared out by Abraham, she is able to see how this way of displaying the ideal gas law indicate that the pressure is inverse proportional to the volume. In this excerpt the students do not discuss the controlled variable of the amount of matter, probably because they do not even consider this to be an issue. This is though discussed in the following excerpts concerning the second experiment, where the pressure is measured as a function of the amount of matter.

The following excerpt is a discussion between Abraham and Abby when starting up experiment 2 (p versus n). The labwork is done by changing the amount of matter in the syringe by detaching it from the pressure meter. The amount of matter in the syringe is detected by reading out the volume on the syringe. The syringe is then reattached to the pressure meter, and the piston is moved till the volume of the trapped amount of matter is the same for each measurement. The pressure is then measured. This causes some problems, since the students are operating with two volumes, namely the volume indicating the amount of matter, and the volume, which the measurements are to be done at.

Here Abraham and Abby have just finished the first experiment of pressure versus volume, and are using the same equipment for the second experiment.

Abraham I don't understand, well, we have a **constant volume**, and then…

Abby …and still we have **to change it**, that is kind of weird.

Abraham And then we have to make **the pressure change with a constant volume**.

Abby I think it is because we have done something with how much or how many **moles there is now** [shows different piston settings on the syringe]. And then calculate it. And then if you do like this for example, and then pull it out till 15 [millilitres], **then there is the same number** [of molecules], **but the volume is still the same**.

Abraham Yes, okay [in doubts]. Or the mole is **the same**.

Abby No, the mole is not **the same**, the volume is **the same**.

Abraham Well, but, oh well, okay, but if we pull it out til 15, okay, yes, I just think, oh well, but like, okay, well enough [in doubt, giving up]

Abby But how? [Reads from the labguide] 'Remove the syringe and pull the piston out or in. Hereby you vary…Instead of the amount of matter here is used…'. Okay, then if you **change** if from 15 before you attach it. If

you now push it down to 15.
Abraham Okay. What would we like to do with this?
Abby Okay, then we would like to **change** this again, right?
Abraham Oh right [mumbles to himself].
Abby Yes [In doubt]. No, because it is not the volume.
Abraham It is the volume which we measure instead. It is therefore we...
Abby No, because the volume is the **same**.
Abraham But, wasn't it...
Abby Yes, yes [in doubt].

What happens in this excerpt is that Abraham poses questions concerning the experiment, not really understanding the role of the different variables, such as both a constant volume and a non-constant volume. Abby has similar concerns. Abby, though is on to something when realizing the amount of matter is the independent variable, and that this can be estimated by measuring the volume. Abraham is still in doubt, wishing the amount of matter to be the controlled variable (the constant), such as it was the case in the previous experiment. Abby corrects this, and Abraham accepts Abby's argument, though not really understanding it. In the following, Abby loses her argument, when blinding herself on the fixed volume of 15 millilitres. Abraham wishes Abby to get back on her previous track, but they end out calling in Alice to explain the experiment.

Each time the students use terms such as *constant*, *change*, *same* it has been highlighted, showing how the students struggle with identifying which variable to alter and to control (they are both clear on the pressure to be the dependent variable to measure).

Though not addressing their discussion directly to Alice's introduction to variable control, it is evident the students are working on this issue and using terms such as *constant*, which was used by Alice in relation to her variable control. Therefore the labwork has made the students go into this discussion, and they are somehow aware they need to identify the variable to alter and the variable to control.

This discussion of variable control is again pursued later (the next labwork day). This following excerpt is taken from the discussion between Abby and Abraham when working on understanding experiment 2 (p versus n).

Alice has given them the task of rewriting the ideal gas law so it fits to the graph they have gained from the measurements. That is the dependent variable p is written on one side of the equation, the independent variable n on the other side and the controlled variables are collected and displayed as a constant (much like it came natural to the students in the first excerpt example). The asked for calculation is this:

$$\begin{aligned} p &= \left(\frac{R \cdot T}{V_{constant}}\right) \cdot n_{varying} \\ &= \left(\frac{R \cdot T}{V_{constant}}\right) \cdot \frac{V_{varying}}{V_M} \\ &= \left(\frac{R \cdot T}{V_{constant} \cdot V_M}\right) \cdot V_{varying} \end{aligned}$$

followed by a calculation of the constant in the bracket. The students are then asked to calculate the value of the constant in proper units based on their measurement of the room temperature T, the molar volume V_M and their knowledge of the gas constant R and compare this to the slope.

Abby But it is, then it is just, it is where, where it was **constant**. So in principle we just have to calculate ... I have totally lost the overview. It has to be something with it **varying**, n **varies**, right. So we have n on this side [of the equation] **standing alone**, and that we can naturally do by multiplying it down. Yes, yes, then it is $p = RT/V \cdot n$, and n **varies** then, **so we have to figure out what that variable is**.

Abraham What, that one?

Abby Yes, and n...

Abraham That one, it is a **constant**.

Abby Yes, but what it then is, that **constant**. And we then know it is the same as $p = RT/V \cdot V/V_M$.

Abraham Which is the amount of matter.

Abby Can you do that?

Abraham I don't know.

Abby Yes but, there is no point in this since we want this to **stand alone**.

Abraham Then take this out, I just don't know.

Abby Then we still can't make this one **stand alone**.

Abraham Well, we want n **to stand alone**?

Abby Yes, we get that there, and then we know n **is the same as there**, so it is fine, this thing. Now we just need to find out its value.

Again the students struggle with figuring out how to handle controlled and independent variables. The students are now clear that the independent variable is the amount of matter, but they are not sure of how to place that in the equation. Abby continues on trying to isolate it, since she expects it to be the proper way to display the graph (as she also wanted to do for the first experiment shown in the first excerpt). When consulting Alice they have previously replaced n in the equation with V/V_M, so since they perceive n as the independent variable, they are now confused it is no longer in the equation. While being quite uncertain, they are still aware of separating dependent, independent and controlled (constant) variables, showing how this point of Alice is picked up by the labwork.

These three excerpts are only a few among several displaying Abby and Abraham's struggle with and development of understanding of independent, controlled and dependent variables, and how these change roles in the tree experiments.

Graphical data treatment
Alice has a second purpose of the labwork, namely what she calls *graphical data treatment*, which she understands as the ability to translate the fit function of a graph displaying measured data to a physics equation, holding physical quantities as well as proper units.

Most of this work with comparing the slope of the graph with the measured quantities is done while the students are making the lab reports at home. Still, the task that Alice has given the students about writing up the equation of the ideal gas law as relevant to the different experiments and determining the value of the constant based on measurements includes elements of Alice's graphical data treatment.

Here the students have finished writing up the ideal gas law in a proper way to resemblance experiment 2 (they settle on $p = (R \cdot T/V_{constant}) \cdot n$), and are now turning towards determining the value of the constant variable $R \cdot T/V_{constant}$. Since they are not swapping n with $V_{varying}/V_M$ and are not aware of the unit of the measured pressure, they are running into problems.

Abby Now we just need to find out what that value is [of the constant in the equation $p = (R \cdot T/V_{constant}) \cdot n$.]

Abraham And then we need the ideal gas thing [the value of R].

Abby Yes, R, and what is R? Didn't it say so somewhere here [looks through the labguide]. I don't know if R is written here anywhere. Well.

Abraham Then what about in the book, then? [Looks through sheets in his folder]

Abby Hasn't we got R anywhere? Did you find it?

Abraham No. That 273, is that to do with Kelvin, or what?

Abby No, 2, no, I can't remember. It probably is. Do you remember where it is, this gas thing? [Looks through the book]. There. There is something here. Well. Here. Did we find out that it was, this thing? Oh, sorry. $8.31 Pa \cdot m^3/(mol \cdot K)$. Yes, it is 73. Is that my pocket calculator.

Abraham No. And then we need that volume. And it was $15 mL$, and we need that in cubic metres.

Abby Yes, and how do we get that? What is that, what is that smart thing you got there [talks about unit converter program in Abraham's pocket calculator].

Abraham Programs. Programs, science to. [Types on his calculator].

Abby Ha [impressed].

Abraham Oi, you have to write p there. Well, I don't know, do we put n in, or should we just calculate it with that one? [Types on calculator]

Abby And then you need a bracket, oh, no, no, that is fine. Yes, brackets around that, or else you divide first with that on that, you need brackets around that.

Abraham No. We don't. But the result is rather big.

Abby No, you shouldn't [Have tested with and without brackets on her own pocket calculator]. That was very weird. Oh, well.

Abraham It doesn't matter, because then you just multiply it with that one.

Abby It gave a very large number, but what was it we calculated? We calculated on a constant. So it could be a large number. [The found number was 163,180,700].

Abraham It has to be equal to the slope of our graph.

Abby [Laughs] No, should it?

From here they continue on converting units to make the number more reasonable in relation the slope of the graph. They do not finish this work before they move on to another task.

In this excerpt Abby states the task, namely to find a value of the constant in the equation, they have previously been working on. To do so, Abraham realizes they need the value of the gas constant. It is given in unlike units to the measured values, and the students then need to convert the constant volume and the temperature, which cause some problems. Finally they reach a result showing how $p = 163, 180, 700 Pa/mole \cdot n$. Abraham interprets it as the slope of the graph, which Abby obviously does not trust, since they are accustomed to slope values closer to one. The problems occur since they have no control of the units, because the pressure is measured in kilopascal and the amount of matter is measured as a volume, and not in mole.

But what the transcript does show is that the students are understanding the task of transforming the constant in the equation to a value equal to the slope of the graph, and that this work include converting units etc., thereby picking up on Alice's *graphical data treatment* purpose and understanding its need for this labwork.

Anita and Annie

Here Annie and Anita's discussions during the labwork are analyzed in order to gain knowledge of their use and understanding of Alice's intentions of *variable control* and *graphical data treatment*

Variable control
In these following transcripts Anita and Annie touch upon Alice's purpose of *control of variables* and related subjects like *variable identification*.

In this excerpt the students have finished experiment 3 (volume as a function of temperature), and are writing in their results in excel for further data handling. They are discussing which is the independent and which is the dependent variable:

Annie Then we start with the temperature, right? [which of the variables to write in the first column, the choice will per default define the first column to be the independent variable]
Anita The volume. We can also do that. **What should be a function of what?** It depends, right? Okay, **the temperature**...

They end out concluding the temperature is the dependent variable, opposed to the general ideal of the labwork. Later they realize their wrong choice:

Annie Should we call it something? The x-axis is the temperature, right?
Anita Oh, yes, yes. But shouldn't we check **what is a function of what?** [...]
Anita Okay [looks in the labguide], V **as a function of** T. Then we have to have V **off from the x-axis**. We just need to change that.
Annie Then let us just swap them.

They change the graph, so the temperature is displayed on the x-axis. They change to experiment 0 before doing any fit to the graph. During this work of displaying the data from experiment 3, Anita and Annie have no discussions of the constant variables and their control of them.

The following transcript is taking from the second day, while the students plot their data of the first experiment (pressure as a function of volume).

After having done the task by pressing the piston of the syringe inwards or outwards to vary the volume of the fixed amount of matter and measure the respective pressure, the data is presented automatically in a graphical representation. Here it is obvious to Anita and Annie to make some kind of fit to the data. In this transcript they are discussing which function to fit to the data.

Anita No, we ought to just look at the **connection** between .... What is it, what is it the **fit function is supposed to be**?
Annie It is supposed to be, to be, auto-something, right?
Anita So it should be **proportional**, shouldn't it?
Annie No, it is **flat**.
Anita But if the volume is zero, don't you think something is...?
Annie No, no.
Anita Then the pressure is too large. You think it is **proportional** then?
Annie Yes [in doubt].

Anita We should be able to see it by that formula. Eh.
Annie It is p times V is equal to n times R times T.
Anita Eh. [Picks up the labguide.] What is the **connection** between V eh?
Annie p and V?
Anita p and V. Well, so p is equal to nRT divided with V.
Annie Yes, you can also say, that if you want these three to be **constant**, then. . . .
Anita But you can say they are **reciprocal**, when they **multiplied with each other gives a number**, right?
Annie Yes.
Anita When they are **reciprocal**. [Turns to the computer.]
Annie Like that.
Anita Then there exist a **reciprocal connection**.

At first in the excerpt Anita knows at this stage she is expected to make a fit to the data. But she is uncertain which function to fit to. Annie responds by talking about a software option called something like auto-fit which provides a number of fit functions such as a linear fit, a reciprocal fit, an exponential fit etc. Anita is obviously expecting the volume and the pressure to be proportional, since they are used to all connections between variables to be linear. Annie replied to this by drawing Anita's attention to the fact the data seems to flatten out for large volumes, and therefore cannot be proportional. Anita tries once again by pointing towards the low volumes, where the data can display a linear functionality with a negative slope ("But if the volume is zero, don't you think something is. . . ?") Annie refuses, and Anita now looks at the larger picture to see if for a proportionality of all the data, and now sees how the pressure for low volumes is way too high for linearity.

Anita asks whether Annie thinks they are proportional, and she replies positive, but there seems to be a doubt in her voice. Anita - also in doubt - turns towards the ideal gas law, which Annie dictates by heart. Anita wishes to have another proof and finds it in the labguide. She is then in doubt of which of the many variables the data displays, and Annie helps out. Now they show two different ways (but of course equal) of thinking about reciprocality, which Alice have both mentioned. Anita needs to isolate the pressure as a function of the other variables and look at the position of the volume in the fraction. Annie thinks about two variables being reciprocal if the multiplied together equals a constant. Since both mathematical representations obviously are true for the ideal gas law and they are able to display their mathematical way of seeing it, they agree upon reciprocality between the volume and the pressure. Now the rest of the task is just to find the name for this function in the software program (which is in English, and the students are only aware of the Danish names for this kind of functions).

In this excerpt especially Annie is in need of believing that the multiplication between the amount of matter, the temperature and the gas constant is indeed a constant for making it agree with her way of understanding reciprocality. For Anita it is not so crucial, since she only focuses on the position of the volume in the fraction that emerges when isolating the pressure in the ideal gas law, and therefore does not think about what would occur if the numerator is not constant. They do not discuss if the temperature and amount of matter is indeed kept constant in the experiment. But they are closing in on it in this excerpt. This (along with the following) is the place in the labwork where the students are closest to discussing Alice's *variable control.*

During experiment 2 (pressure as a function of the amount of matter), Annie and Anita close in on variable control.

Annie First we should do like before, but the difference is we take if off [the pressure meter from the syringe] and then we do like this, and then we screw it back on, right, because then there is this amount of gas in here, and then…

Anita Oh [understanding], **so it is the amount of matter** [that varies]. I understand. Then it has nothing to do **with the volume**.

Annie And then we do like this [move the piston], and then we measure the pressure.

Anita Do we move it to the **same volume**, but with **a larger amount of matter**?

Annie Yes. And then we write it here, it is the volume of the amount of matter there is trapped in there. Now we just write the volume, because that is what we measure. We measure this one with 15. […]

Anita [Bad audio] to **change**. One of them is called n. The first thing we should do is 'experiment data collection' [a software menu], and then we need 'entry', well, it isn't **the volume**, but it is n.

Annie Yes, I know, but it is **the volume we measure**, and then we calculate n afterwards.

In this excerpt they discuss the independent and controlled variables of experiment 2, which caused Abraham and Abby so many problems. Annie starts out being certain of the role of the variables, but Anita is the one making the issues fairly explicit by stating how the amount of matter is the independent variable, and the volume is the controlled variable (though in her own words).

As seen from these excerpts, Anita and Annie are fairly clear about the role of variable control (and related variable identification), and its connection to the done experiments.

Graphical data treatment

Alice's second purpose about *graphical data treatment* is also directly addressed by Anita and Annie. They though do not get as far with it as Abraham and

Abby, since they somehow misinterpret Alice's intentions of making them calculate the value of the constant and compare it to the graph slope for each of the experiments 1, 2 and 3.

After having taking in all data the students asks Alice what to do next, and Alice gives them the same task as Abraham and Abby about translating the ideal gas law to each of the experiments; calculate the value of the constant and compare it to the findings of the graph fit. This includes a lot of unit conversion. Annie and Anita find time to consider all three experiments by focusing only on the units conversion of the task, and thereby misinterpreting most of Alice's task.

First they calculate on the first experiment (pressure as a function of volume):

Anita What was it the first experiment was about, the one we made. [Looks in labguide.]
Annie Okay. It is just the same [as experiment 2].
Anita [Writes 'Experiment 1' and the ideal gas law on a piece of paper.] $p = nRT/V$, where nRT is a constant. [Writes '$nRT = c$']. And p, what do we measure that in?
Annie That stupid temperature. [Annie looks at the computer] Kilopascal.
Anita Good, yes [Writes 'SI units: $p = kPa$'].
Annie Well, what do we measure R in? [Looks in notes.] R measures in that.
Anita What did we measure n in? It should be measured in mole, right? [Erases '$nRT = k$' and writes '$p = (nRT)1/V$'] We need to calculate that, we haven't calculated that, that over there we have calculated. But we need to calculate it to mole.
Annie What?
Anita Mole times that is... times T, what is T measured in? [Writes '$kPa = mol \cdot Pa \cdot (m^3/mol \cdot K)$']
Annie T measures in Kelvin.
Anita [Writes '$kPa = mol \cdot (Pa \cdot m^3/mol \cdot K) \cdot K$']. Kelvin, I guess that was what we measured it in.
Annie No, it wasn't...
Anita Oh, how was it again?
Annie Maybe you shouldn't when it is the equation of state of matter.
Anita And divided with V which is measured in millilitre [Writes '$kPa = mol \cdot (Pa \cdot m^3/mol \cdot K) \cdot K/mL$']. Yes.
Annie [Laughs.]
Anita But it is that one we have to find. Well, it is multiplied with mole that goes out, so it is Pascal times cubic metres. [Writes '$Pa \cdot m^3$'.] And what did she say again, it was something we should do...

As seen, they write up the ideal gas law in a proper way and clarify what is constant, and thereby implicitly the independent and dependent variable. The rest of the transcript concerns recognizing the units of each of the formula components and doing some work on converting them.

At this time Alice is called in to check their results, and the rest of the discussion focuses purely on unit conversion. Alice tries to make them focus on comparing the calculated value of the constant to the measured slope of the graph, but this is not picked up by the students, and they never solves the problems of finding values (besides the unit) of the amount of matter (along with the gas constant and the temperature).

Now being confident the task is to convert the units for the three experiments, the students continue this work with the second experiment (pressure versus amount of matter) and the third experiment (volume versus temperature). Since they only care about the units and are not taking into account the amount of matter is not directly measured, they just have to repeat what they did for the first experiment. For the third experiment (V versus T), they have the following discussing:

Annie This is experiment 3. [Looks in labguide.] It has to be that V **is a function of** T. It has to be that V is equal to n times R divided with p times T.
Annie What did we measure in? Did we measure in degrees, no, we measured in Kelvin.
Annie That we measure in Pascal, right? That there. So it is. . .
Anita pV is equal to RnT, right?
Annie Yes.
Anita [Writes in labguide.] V is equal to RnT divided with p, like that.
Annie No, like that.
Anita Is it that thing with p times T.
Annie I just included T.
Anita Yes.
Anita V is equal to Rn divided with p times T. Like that. Good. Well n is proportional. [Mumbles to herself]. Ehm. Okay. So R is measured in the same? In Pascal times cubic metres divided with mole times Kelvin?
Annie Yes.
Anita And n is in mole, and then it has to be divided with Pascal. Then Pascal goes out with Pascal.
Annie We measured that in millilitres, right?
Anita Then it is just cubic metres pr. Kelvin. That can just be converted to millilitres.
Annie Yes. That is [mumbles] millilitre, then it must be [mumbles] over Kelvin.

Since now the pressure is intended to be constant, the students feel the need to rewrite the ideal gas law so that the volume is on one side of the equation. When this is settled, the students can continue with their unit conversion, not taking into account the magnitude of their variables, and are therefore quickly solving what they perceive as the task.

Due to the misinterpretation of most of Alice's task, the students do not get through all of Alice's intentions related to *graphical data treatment*. They are able to relate and convert the units of the independent and dependent variables, but are not taking into account how to operate with e.g. the amount of matter.

Halfwidth

Derek has presented the labwork as an activity to enhance the understanding of systematic and random uncertainties. The students address these concepts a number of times, both by stating it directly and by discussing it by use of different terms.

First instance is while setting up the apparatus. Daisy asks the teacher Derek about the distance between the radioactive source and the GM-tube:

150 **Daisy** Derek, it doesn't matter what distance there are between them [the GM-
151 tube and the radioactive source], as long as we keep it constant. Or does
152 it? Or would you like to…
153 **Derek** Well, try to consider it. Whether it matters?
154 **Dana** It is a **systematic**…
155 **David** For sure, the further away you get, the fewer rays will enter.

Here Dana tries out the concept of systematic uncertainties, but it is not completely sure what she means with it.

A few minutes later, the students again make use of the concept when discussing a GM-tube that does not seem to function:

237 **Daisy** The tube, it doesn't seem to count.
238 **Derek** You can for sure say that is a source of error.
239 **Dana** Yeah, a small one.
240 **Daisy** Yeah, a large one.
241 **Derek** Last time there was some of the other tubes that didn't work.
242 **Dana** That is fairly **systematic**.
243 **Derek** Exactly.

Here Dana has more success in her use of the concept of systematic uncertainties, and she gets credits from her teacher for it, though the entire discussion is ironic.

Later, the students have measured the background radiation and start to measure with increasing amounts of lead plates. When placing the ninth lead plate, they record a drop in the count number that is larger than they expect (based on detecting an unaccounted for pattern in the data, they have still not tried to plot the data).

David Then between nine and eight [plates] it just jumped between 27 and 12. What the fuck!
Daisy No, let's try it again, just one more time.
Dana But they are equally thick, these plates?
David Nature is very unstable, very unstable.
Daisy Dana, try to. . .
Dana But are they equally thick, these plates?
Daisy Yes.
David Yes, yes.
Daisy They ought to, at least.
David It is the grease of Dana's hands that cause it to go crazy. Are you trying the same thing again?
Daisy Yes.
Dana Yes, now it is at 16. Then try again, maybe it will increase again.
David Try again, maybe we will win the lottery [ironic].
Daisy No, but this is cheating.
Dana Don't worry, we only have it on camera [ironic]
Daisy No, now it is 16.
Dana Yes, 16 of the good ones.
Daisy That was nine plates.
David Try with eight plates again, I would like to repeat that measurement.
Dana 8, 1, 2, 3, 4.
David But try to see, 26, it fits very well, before we had 27.
Daisy Yes, yes.
Dana But it can't be true that one plate should do all that difference.
Daisy Well, it could thought.
Dana Are you sure it is a 2 millimetre plate?
David Well, do you want us to repeat measuring it over and over, you can see it is the same, right.
Daisy Well, I think one plate can make such a big difference.
Dana Such a big difference?
Daisy Well? [. . .]
David Are we still having nine plates?
Dana . . . but it is a **systematic** one, isn't it?
Daisy No, it is a **random** one, because it was in the middle of it, just suddenly.

Again Dana tries to explain the detected phenomenon by use of the concept of systematic uncertainty, but Daisy corrects her when in her own words stating that systematic uncertainties play in on all the measurements and not only one of them, and therefore the unexpected phenomenon most be due to random uncertainties. They repeat discussing their unaccounted for data:

Daisy No, but David, they are . . . , it is **random**. That is also what it says. That is like. . .
David But it is really weird. If we draw this curve, then it will look like this [draws a graph on a piece of paper]. It decreases slightly, and bang, then it is way up here, and then it decreases the rest of the way, it will do like this, wup, wup.
Daisy And then the other[?]
David It doesn't even, well, it decreases here, and then it will do like this, and then make such a. . .
Dana Yes. Well, I guess we have something to write in 'Sources of errors'.

Daisy, having success with explaining it as a random uncertainty tries to use this as the valid explanation of the data, but David does not accept this. Dana accepts Daisy's explanation when closing the discussion by referring to the section of sources of errors in their lab reports.

At another instance, David detects that Dana has moved the GM-tube, and it is obvious to David and Daisy that it will cause uncertainties to the data:

David Have you now moved that counter?
Dana Well [obviously she has].
Daisy **Uncertainties** [laughs]

They end out by repeating all the measurements without changing the position of the GM-tube.

Introducing the concepts of random and systematic uncertainties in relation to the halfwidth labwork have made the students try out and use the terms in the situations where the data deviate from the expected pattern. Since the students did not have time during the labwork to fit the data and extract a measured value of the halfwidth, the idea of systematic uncertainties in relation to a smaller or larger measured value of the halfwidth was not displayed in the discussion, but comes up in the lab reports.

As seen, the students are uncertain of the use of the concepts, but are trying them out on each other and thereby gaining a larger understanding of the them.

8.3.2 Low level of declaration

The transcripts for the cases of a low level of declaration (Burt's two groups and Derek's halftime group) are investigated in order to detect sayings related to the found potential learning outcomes of the labwork activities, such as discussed in section 8.1.1 and section 8.1.2. Also, the data have been investigated in order to detect discussions related to posing questions or expressing knowledge about the data in relation to physics (the excerpts that have been categorized as KTP).

Bridget, Brit and Brianna

A number of the potential learning outcomes in the procedural skills domain - such as discussed in section 8.1.1 - are addressed by Bridget, Brit and Brianna during the labwork activity concerning conservation of the mechanical energy. These are *repeatability*, *variable identification*, *fair test* and *sources of error*.

First *repeatability* is addressed. This excerpt is from when the students repeat their first measurement of the pass time:

Bridget Then let's see what it says. Funny enough it says 13.42 again. Hi hi. Then I guess it is correct.
Bridget [Sets up again] Just to be sure. Like that. And 13.42.
Burt Do you more or less get the same pass time every time?
Bridget Yes, precisely the same.
Burt That is very comforting.

The excerpt shows how the students are surprised - but also pleased - that their measurements give exactly the same result. To them it verifies that the measurement is "correct", since they are still not sure uf the setup is functioning as it should.

In the next excerpt the students touch upon *variable identification* and *fair test*, when they are discussing what to change after their first measurement (with three repeats). The labguide discuss different positions of the photo cell, different pull weight masses and different load weight masses (and touch upon different flag lengths):

Bridget Then we can try with some **different distances with all of the three pull weights**.
Brianna What?
Bridget Yes, now we have three measurements we can do with **different distances**, and then we can also try with **different weights**.
Brianna Don't you think they all should be at 117 [the position of the photo cell], so they can be the same, **because else we cannot really compare them.**
Bridget Yes, let's do that. And then just with **different pull weights**.

It seems in this excerpt Bridget wants to change the position of the photo cell first, whereas Brianna prefers to change the pull weight masses first. This is first a discussion of which variables that are possible to alter (they discuss distance and pull weight masses as possible independent variables). Brianna then touches upon variable control when talking about being able to compare data.

This following excerpts touch upon *repeatability* as well as *sources of error*. The students have now changed the position of the photo cell and have done one measurement series, and have just changed the pull weight. They discuss if the pull weight hits ground before the cart's flag passes the photo cell:

408 **Brianna** It hits.
409 **Bridget** No, it has been cut off.
410 **Brianna** Yes, but while on the floor. It has to go higher.
411 **Bridget** Try setting it up higher, then we see **if it gives another result. And if**
412 **it does, we just repeat it**.

The students are aware it is a problem if the pull weight hits the ground before the flag has passed the photo cell. Bridget states they should shorten the string and repeat the measurement. If the measurement of the pass time is unaltered, then everything is fine, and if it is different, then they just have to repeat the measurements with the new length of the string. This shows an understanding of the importance of repeatability, as well as a discussion of the potential sources of error the labwork hold, which they should try to prevent.

Additional KTP codes
These three excerpts above show they students touch upon repeatability, variable identification and variable control, as well as sources of error. The rest of the transcript parts coded with the KTP category are primarily predictions or comments of the pass time measurements, such as:

244 **Bridget** No, it is not coming as fast this time. [...]
289 **Bridget** It will probably go rather slow, when the pull weight is so small. [...]
374 **Bridget** Now it had time to go faster. [...]
389 **Bridget** 49.8. But I guess we can also make the cart heavier? [Addressed to
390 Burt].
391 **Burt** Yes, and if you want to do that, then we do it. Then we just put some
392 weights on the side of it.
393 **Bridget** Should we make the cart heavier?
394 **Brianna** Let's try that when we are finished with this.
395 **Bridget** Yes. Then it could be it is too fast if we put the 100 weight on. [...]
405 **Bridget** Like that. [Makes new measurement]. Now it is fairly fast. 13.517.
406 [makes new measurement]. [...]
459 **Bridget** Now it is really much slower. 23.164.

This indicate a somewhat good understanding of how different pull weights and load weights will change the speed of the cart, but these are never addressed in relation to concepts of kinetic, potential or mechanical energy.

Generally, the students have very few statements indicating an understanding of the design of the labwork, the data and results, the labwork's relation to mechanical energy, and the learning goals of the labwork.

Bob, Bonnie and Bobbi

As for the previous group, also the transcripts from the group of Bob, Bonnie and Bobbi are looked into to find evidence of reflections upon some of the sub-skills of the procedural domain, which has previously been found as potential learning outcomes of this labwork task. Transcript excerpts have been detected, which touch upon *fair test*, *repeatability*, *accuracy*, and *uncertainties and errors*.

In the first transcript, the last three sub-skills (*repeatability*, *accuracy* and *uncertainties and errors*) are addressed. After having encountered some problems making the counter work, the students finally get some numbers out. When repeating their first measurement they get exactly the same number which makes them uncertain if the counter is working:

Bonnie It is very strange [bad audio].
Bob It is very **accurate** then, this thing we are doing [bad audio].
Bonnie There is no **sources of error**.
Bobbi 10, 11.8 [bad audio].
Bob What?
Bobbi [Bad audio].
Bob 11.8. What the hell are they doing? [The girls walk over to Burt].
Bonnie We put it to measure it, and then we changed it to the place you said we should, right, but then there is only a new result in one again, and it is **completely the same as the previous**. And that is kind of **unrealistic**.

First, Bonnie and Bob discuss accuracy, as they find it to be very strange if the accuracy of the labwork is as high as they are measuring it to be. Bonnie is relating this to sources of error, which she states must be non-existing for the case of perfect repeatability, wherefore she touches upon *uncertainties and errors*, and is obviously not aware of systematic uncertainties and uncertain ranges.

After this the students starts to measure, and are now discussing how come the data with unchanged conditions are varying, and how this relates to different sources of error:

Bobbi In principle it can be faster, if you wait for a longer time. If just before the air was not as powerful [talks about how long time the motor to the air track has been on].
Bonnie But we waited for the same amount of time each time.

This short excerpt shows how Bobbi is able to reflect upon the non-repeatability of the measurements in relation to different sources of error. Bonnie replies by arguing for control of that variable, which then cannot be the cause of the varying measurements.

In the following excerpt they are discussion how accurate the data should be to expect the experiment to be repeatable:

549 **Bonnie** They are actually pretty close, after all.
550 **Bob** No, it is not. You just need to align it [about the flag]. [Makes measure-
551 ment].
552 **Bonnie** 25.396.
553 **Bob** Shouldn't we repeat it to see if we can get one closer to 25. It has to be
554 24.
555 **Bonnie** No, they are pretty close anyway.
556 **Bob** The others are close, the other measurements.
557 **Bobbi** Are they?
558 **Bob** No, okay, maybe not.

Bonnie and Bob are not agreeing upon the accuracy level, and Bob is trying to make them repeat the experiments till they have three measurements, which is close enough within his criteria for accuracy. Bonnie has other criteria and wish for them to move on.

In this excerpt Bob believes the problems of *repeatability* is caused by a source of error in how the cart is released:

615 **Bobbi** There is a large difference.
616 **Bob** I believe it makes a difference when you hold it like this [talks about the
617 cart to Bonnie]. Then it tilts.
618 **Bonnie** Does it tilt when I do like this?
619 **Bob** It did just before. Try it again.

Bobbi starts out by recognizing their criteria for repeatability is not met, and Bob looks for a reason. Bob is suggesting repeating the experiment when being aware of a possible tilt in order to see if the cart was tilted in the previous measurement.

Additional KTP codes

The rest of the transcript parts coded with the KTP category are primarily predictions or comments of the pass time measurements, such as:

310 **Bonnie** Before it was something else. [...]
459 **Bob** Does it go even faster now? [...]
638 **Bobbi** But it is very large difference, when it was [bad audio]

As was also the case of the previous group, these small excerpts along with some of the above excerpts indicate the students are having some reflections on the numbers they get, and how they are relating them to the setup (different weights etc.). Also Bob, Bonnie and Bobbi are not discussing these in relation to kinetic, potential or mechanical energy.

Bob, Bonnie and Bobbi discuss repeatability a number of times, and relate this to issues of accuracy, uncertainties and errors as well as variable control. It seems though they are not having a vocabulary to discuss these issues on a higher level, and are not relating these discussions to learning goals of the labwork activity. Their concern is primarily to get good enough data for writing a nice report.

Halftime

For the case of Derek's group doing the first labwork concerning halftime and radioactivity, the students touch upon a number of these sub-skills, which has previously been recognized as potential learning outcomes of the labwork activity (see section 8.1.2).

Instances where the students to some extent touch upon the sub-skills are recognized within the categories of *variable identification*, *relative scale*, *repeatability*, *graph types*, *patterns*, *units*, *equation translation* and *uncertainties and errors*.

Having finished with their taking in of data the group plots them in excel. Here they touch very briefly on *variable identification* and *graph types* when discussing what to have on the x- and y-axis.

616 **Daisy** Then we have the x-axis here, like that, yes.
617 **David** Then you should do a...
618 **Daisy** Then the x-axis - that is minutes. And the y-axis, that is the radiation.

As seen, Daisy is sure what to place on the axes, and have no concerns about the type of graph, since it is obvious to her to use an x-y plot.

The students redo their measurements after having handled the data from the first measurement series and found them lacking information. In this excerpt the students touch upon *relative scale*:

1227 **Daisy** Okay, yes. Then we need some radioactive liquid.
1228 **David** And it is the same mounting, so there is not difference on the height?
1229 **Dana** Yes, yes. [...]
1280 **David** Get out of here, it is some completely different numbers we get now.
1281 **Dana** Stop it David.
1282 **David** 275. Well, before we got 101...
1283 **Dana** Yes, yes.
1284 **David** ...as the highest, it is completely insane. Hurry, hurry, got damn Daisy.
1285 **Daisy** Oh shit.
1286 **David** It decays.
1287 **Daisy** And now. [Every time 10 seconds have passed, they write down the count
1288 number, and Daisy holds track of the time]. Now. And now. And now.
1289 And now. Now. Whoaw.

1290 **David** There is exactly 100 in difference. Get out of here. Get out of here.

First the students discuss the position of the GM-tube, and David assures the others that nothing has been changed on the mounting, implying similar intensity values compared to the previous measurement series. Therefore they are quite surprised when they start measuring and find the intensity level is significantly higher. They do not get around to discuss why the intensity level has increased (shorter pause before measurement start and/or larger amount of radioactive liquid), and they are not getting all the way there in discussing *relative scale*, understood as the affect it might have on their data handling when the measured intensity values are higher.

While doing measurements on the background radiation, the students touch upon *repeatability*:

244 **Daisy** This is weird, then it suddenly measures four, and then it is just zero.

Apparently Daisy expect the background radiation to take the same value in all measurement time intervals, or at least with a lower deviation value than four.

The students also touch upon *units* during their data handling.

1357 **Daisy** Yes. How many are there. How many should there be. David? How
1358 many seconds are there in 5 minutes? 60 times 5. 1, 2, ...
1359 **David** It is just 5 minutes; you should divide it in 30 parts. Yes.
1360 **Daisy** Yes.
1361 **David** It is 300 seconds.
1362 **Daisy** Oh, yes. That is okay.

They are in their data handling juggling between minutes, seconds and 10 seconds, trying to figure out how to handle the data.

When handling the data, the students touch upon *patterns* when discussing what to fit to and if the data display the theoretically expected pattern:

668 **Dana** I guess it is an exponential?
669 **Daisy** Options, oh, there it was [talks about what button to push].
670 **Dana** Shouldn't it be 'regression'?
671 **David** There it was!
672 **Daisy** Oh, yes, yes.
673 **Dana** Exponential, press exponential. Now you chose linear.
674 **Daisy** 'Add trendline'. Then we just have to choose 'R'.
675 **David** Where did you find that 'trendline'?
676 **Daisy** 'R', 'R', there. 'Add trendline'. I can't. Yes, we see it.
677 **David** Okay, it is not a complete pattern, is it?
678 **Derek** No, but it twist and turn.
679 **David** It looks good.

Besides the discussing of which buttons to press, in this excerpts they choose on fitting the data to an exponential function, and in the end David question if the data actually display the expected pattern, but ends out stating the data looks good.

The students discuss *equation translation* when trying to extract the decay constant (and thereby the halftime) from the fit equation. First David tries to convince the others to read of the halftime directly on the graph, but Daisy turns the discussion towards the fit equation:

834 **David** I would look at, look at, yes, how long time it takes for it to go from, if
835 you, I guess we should look at when the radiation is half.
853 **Daisy** But now we have just got this equation and that has maybe something
854 to do with each other.
861 **David** But isn't then in reality what it says up here?
862 **Daisy** Yes, that was what he talked about. I have just notices that it is e, that
863 is e
864 **Derek** To minus that which is in x.
873 **Daisy** Try to see, here they just put [looks in school book]. Our start value,
874 and then what we have in the beginning. And then e raised to this here.
875 And this is then...
876 **David** But in the decay constant, which we do not have anyway.
877 **Dana** Yes.
878 **Daisy** Could it be that it was this one?
879 **Dana** But, I don't know, because...
880 **David** Let us try, let us try to give it that value.
881 **Dana** 22.1%
882 **David** No, no, the decay constant minus 0.221 seconds raised to minus one.
883 **Daisy** Why raised to minus 1?
884 **David** It is just the way it is.
885 **Daisy** Times t? Well, okay.

After this they call in Derek to ensure them on how to connect the fit equation to the decay law. Apparently they are aware that the fit constants of the regression should give them access to the halftime, but are not sure how to do so, especially since the halftime is not directly displayed in the decay law, and they are therefore needing to determine if they should extract the decay constant from the fit constants or find it in a data table.

Just before the first measurement of the halftime the students touch upon *uncertainties and errors*:

328 **David** It is just a source of error, because when we press it through then we
329 first of all have to be fairly fast at it. Second, now we don't know where

we put the cup, so now it will be in another position.
Daisy No, but the distance will be the same.
David Oh right, but it could still be that it is kind of a source of error.

David is sure it will be a problem if the cup is not placed in the same position as it was when doing the measurements of the background radiation (when it did not hold the radioactive liquid). Daisy rejects his concerns since the position of the GM-tube will not be different. Later they again discuss *errors and uncertainties* on a meta-level:

David Mega sources of errors are emerging for this labwork.
Dana Sources of error is good.
Daisy Yes, yes.
David Lots of them.
Dana Then you kind of know, . . . then you kind of show that you know something.
David Or that you haven't done the experiment properly.
Dana Stop it, you know that you know. You show something.

Here Dana advocates how a long description of sources of error is a way of showing understanding of a labwork, and David teases her about it.

As seen, the students touch upon a number of the potential learning outcomes, which was found in the analysis of the labguide. Still, all of them could be taken to a higher level, and their vocabulary and understanding of the sub-skills have a large room for improvements.

8.3.3 Summary

The three labwork activities with a high level of declaration showed how the students are working with the teacher's intended learning outcome during the labwork, and are struggling with figuring out how to operate with the new concepts and their use. They are all relating it directly to the labwork, which they are in the middle of doing, and are not discussing the issues on a general level. Their understandings develop during the labwork, and before the labwork activity ended all three groups have a fairly good understanding of the concepts and skills which the teacher intended them to reach.

As it could not be the case that the students' not even addressed the teacher's intentions - since some of these are on related to the data handling possibly first done when the students work on the lab report at home - it is of value to see how they address the issues and develop their understanding of them in the lab reports.

For the case of a low level of declaration it is more difficult to decide upon what to look for. The labwork activities were analyzed in order to detect potential learning outcomes, and then the transcripts were investigated in order to find evidence of these learning outcomes. A number of them were found in the transcripts, but typically the students were clearly not having a vocabulary to operate with these issues, as well as not taking them very far. Also the transcripts were looked through to see if anything were missed, and the found instances typically centred around the conceptual domain (or patterns), discussing differences in the data as a function of new conditions.

To conclude upon this the students take up the teacher's intentions during the labwork if these are declared. When this is not the case the labwork itself gives the students the possibility to discuss some of the procedural sub-skills, but the students are lacking vocabulary and reason for taking these discussions very far. It seems likely that an enhanced level of declaration prior to the labwork could increase the quality of the students' discussions of the potential learning goals of the labwork activities.

8.4 Student interviews

After the labwork activities student interviews were performed. In this section interview excerpts are given when posing questions about their teacher's purposes of the labwork task. Interview guides can be found in appendix B.

8.4.1 Abraham and Abby

Two student interviews with Abraham and Abby were done just after each labwork day. The first interview focused on their educational choices, their ideas of the future, their interest and perceptions of physics as an educational discipline, and finally about their attitudes towards labwork activities generally. Here it became clear both Abraham and Abby were contempt with their choice of physics on an advanced level, and that Abraham wished to continue studying physics after the Gymnasium, whereas Abby are not sure of her future education, and does not expect to pursue an university degree.

The second interview focused on the specific labwork as well as the students' perceptions of labwork activities as generating general education. Here they also discuss the similarities and differences between physics and the other science disciplines.

In the first interview Abraham and Alice describe how they perceive labwork activities as an important part of the discipline of physics, and could not be converted to demonstrations or purely written assignments.

LBJ *What about the labwork activities you have had here? Should you do those in the Gymnasium? Or could you just have had them as demonstrations* *or theory. . . ?*

Abby No, you couldn't.

Abraham No, because I think it is pretty good here in the second year, where we are starting. . . Now it wasn't like that today, but we have started on like designing the experiments. It is a good preparation to studying physics at university or doing research. To find out ourselves how to put up the experiments. Not always. . .

Abby Oh, I think it is so difficult. But, yes.

Abraham It is crazy difficult, but it is very good to learn.

Abby I think it is pretty relevant to have some which are not demonstrations. Because now we are sitting here trying to make it work. And you don't if it is the teacher standing and explaining it all. It is like when you are writing a report - independent of the discipline - and then you like understand what you are writing about, because you care enough to do it. . . Well, if you make a good report, then it is because you have spend time on it and understand it yourself. It kind of sticks, at least for me it does.

After this excerpt they continue on discussing the need to have done the setting up and measurements themselves in order both to understand the data handling, but especially to understand if the data differs from the expected values.

Here it is seen how the students perceive the labwork activities as an important part of the learning of physics, which they do not want to be without. Half of the argument is thought that the report writing gives access to an enhanced amount of time spend on physics, and thereby letting more 'stick'.

In the second interview the students are asked to describe the labwork.

Abby We have tried to find out. . . we had to deduce the ideal gas law without knowing it, kind of.

Abraham The equation of state,

Abby Isn't that the same?

Abraham I don't know.

LBJ *I understand what you mean.*

Abby The equation of state. But aren't it also called the ideal gas law?

LBJ *I know it as the ideal gas law.*

Abraham Okay. And then we have varied different things, and measured on it. And seen some connections.

Abby We have only varied two things at a time. To like, to. . . Varied one thing, like the pressure or something else that depended on it.

Abraham We have found connections between different quantities.

Abby Yes, and then we are going home to find out, if we can figure out how to make the equation of state. Isn't that what we are to do?

Abraham Yes, I think it is.

Here they start out describing the labwork not as verifying but deducing the equation of state. To do so, Abraham describes how that is gained from finding connections between the quantities, and Abby describes (somewhat vaguely), how this can only be done by controlling all other quantities than the independent and dependent variable. Still, they are not all the way there, and some work needs to be done when returning home to make the report.

Also, in the second interview the students discuss Alice's intended learning outcomes of the specific labwork:

LBJ *What do you think Alice wanted you to learn from these experiments?*
Abby She said so in the beginning. To do variable control and ... understanding that equation and ...
Abraham We learned some methods to verify something, and of course we will get to understand something...
Abby ... yes, graphical data treatment.
LBJ *Now you are just listing them. Does this labwork bear the marks of those things listed, and which you named here? Do you see that... ?*
Abby Well, we are doing a lot of graphs. So yes. We have also worked with that before. And control of variables that is like essential. And ..., now I can't remember the last thing.
LBJ *Understanding the equation of state.*
Abby That is also fairly central, so yes, it is quite logical or realistic goals.

As seen, Abby is able to list Alice's three purposes by heart, whereas Abraham looks for the more official aim of the labwork, namely verifying the ideal gas law. For Abby, these three purposes are the logical learning outcomes of the labwork, so in that sense Alice's intentions are fully accepted as relevant and related to the specific labwork.

As seen from these three excerpts, they students feel they learn something valuable from labwork activities, which they could not have gained from other types of teaching. They have a very good understanding of Alice's purposes of the labwork task, and they are both finding the purposes valuable and are seeing a clear connection to the design of the labwork.

8.4.2 Annie and Anita

Two student interviews with Annie and Anita were done just after each labwork day. As was the case of Abraham and Abby, the first interview focused on their educational choices, their future education, their interest and perceptions of physics as an educational discipline, and finally about their attitudes towards labwork activities generally.

In the interview they expressed their contempt with their choice of physics on an advanced level, though not wanting to pursue an academic education in physics. Anita expects to start at medical school. Annie is vaguer, expressing a desire to become an actress. She, though, perceives a university education in physics or chemistry as a possible back-up plan, if her actress ideas fall through.

The second interview focused on the specific labwork, as well as discussions of the similarities and differences between physics and the other science disciplines in the Gymnasium.

In the first interview, Annie and Anita discuss labwork activities generally, and how they are not liking the experimental work and the report writing:

Anita I believe I think that the most difficult is experiments, sometimes. It can be difficult, I think.

Annie To get the reports written - that is difficult.

Anita It can be easier, if only... Just learning an equation by heart and plug in numbers - that isn't very difficult. But I think it is more difficult when you like need it to work - when you need to set up the experiment yourself.

Annie So, I hate to write reports, I think it is an awful thing. Can't we just make written exercises?

Still, Anita later state it is during report writing her understanding is formed:

Anita Well, reports and experiments - that is where one really gains understanding. When you have to write a report which is cohesive, then you need to understand it somehow. Well, then you get... then I think you get a broader understanding of it, instead of just learning an equation, e.g.

So though finding labwork tasks and the appertaining report writing difficult, they know it is a good way to learn physics.

In the second interview, Annie and Anita are asked to explain the labwork:

Annie Well, we have measured the different... well we had to find out about the equation of state. Now, we haven't calculated anything yet. And then we did some different experiments where we, well, had different variables. Because you can only... The smartest is only to have two variables at a time, because else you don't know what you are measuring.

Anita But you can't make any experiments at all if you do not have two variables. Then you don't ... then you don't know at all how it is, how it works.

Annie No, then you don't know. If you change on one of them is that then what changes the other, and so, yes... It isn't very smart.

Anita No, but like, hasn't it been nice to do like that... You at least get a good understanding of the connection between those various quantities - I think - in the equation of state.

Annie Yes, I agree.

Anita Also, when you do the graphs, then you also understand. . . or I don't know. Then I think it is easier to understand the connections. Especially when Alice forces us to try to look at the value of the constant.

Annie Yes, and also the units.

Anita Yes, it is very good to do the calculations.

Here they both discuss control of variables, though not naming it like that, thereby hinting how they perceive this labwork as being about learning variable control. They also discuss graphs and how you understand connections between variables when displaying data graphically, including unit conversion.

Later Annie and Anita are asked for Alice's intended learning outcome of the task, and here they are not as clear about her intentions as Abraham and Abby:

LBJ *What do you think Alice meant you to learn from this labwork?*

Annie Well, how it relates. Get a larger understanding of how, yes, how the different quantities depend of each other. And find out. . . , find graphs for the different things. We also need to do that. And see how it all connects. Because, well, it could easily be [bad audio], and then you would say 'oh' [understanding]. But to show that physics is a more practical discipline than mathematics. And show it is actually how it connects.

Anita Yes, I think so too. The connection, yes.

They talk a lot about connections and relations, which could hint some understanding of variables, though quite vague. When confronted with Alice's three purposes, their answers are somewhat difficult to interpret:

LBJ *Wednesday last week she wrote up three goals on the board for this experiment. Do you remember those?*

Annie No, but I probably wrote them down.

Anita No, I can't remember. Wednesday last week, I am not even sure I was there, actually.

Annie I believe you were.

LBJ *What she wrote on the board was for you to gain an understanding of the equation of state, of course, as you just said. To get a sense of variable control and to gain more skills in graphical data treatment. Are those goals achieved?*

Anita I am sorry, can I hear them again?

LBJ *Yes. 1) The equation of state. 2) Variable control, that think about when doing an experiment, then you cannot vary four variables at a time, then you do not know what depended on what. And the third thing was to be better at graphical data treatment. That was her three goals for this labwork.*

Annie I think that. . .

Anita I think it sounds, I really think. Both, I think... Well, not even data treatment - I don't think it is easy. You just need to learn what to do and understand it. You need to understand it. Somehow, before being able to do it.

Annie But yes, I think, it is... Well, of course it is there when we work on the three graphs we have made. Then of course we get better. But yes, I think so.

Anita Me to.

They do not link those purposes of Alice to their own discussions earlier in the interview about variable control and graphical representations, as if they understand the ideas behind the word, but has given these understanding different names.

Annie and Anita are not very fond of labwork activities and report writing, but perceive them as a good way to learn physics. They understand Alice's purposes of the labwork as important issues of the labwork itself, and not as something Alice placed on top of the labwork. When confronted with Alice's purposes, they do not recognize them as strongly relating to their experiences with the labwork.

8.4.3 Bridget, Brianna and Brit

One interview was done with Bridget, Brianna and Brit one hour after the labwork activity. The interview guide can be found in appendix B, and besides focusing on their educational choices, their expected future educational choices and their perception of physics and physics education, the interview focuses on the specific labwork in play concerning mechanical energy.

Brianna wishes to study engineering or going to medical school. Brit chose the physics/mathematics branch since she expected to study to be a dentist, but is now considering becoming a graphical designer. Bridget considers becoming a vet, but is scared her grades will be too low, and her backup plan is to become an engineer.

First the students discuss how they perceive labwork activities generally:

Brit I think it forms a good picture of it, and it makes it more fun than just sitting down in class. I easier understand when having tried it and have had it in my own hands. And see it happening.

Bridget Very good to verify what you have deduced theoretically. It actually is like that because of that and that, it kind of support each other. [...]

LBJ *How do you like making reports?*

Bridget Again, it is here you dig deeper into it and really drive it home.

Brianna I guess it is like there where you kind of think it through, oh okay, like that. I think.

Brit It is all or nothing if you understood it or not. It becomes very clear. You can't talk yourself out of it. You have written what you have written, and then it is right or wrong.

Bridget There is also the thing that the reports are nice to have for e.g. the exam. Then you can sit with some subject and go back and find a certain report instead of looking through one billion notes. Then it is easier to see, oh okay, it is like that. So it's nice for later.

As also Alice's students talked about, they perceive labwork activities as important and necessary for learning physics. Brit talks about the fun of working differently from sitting down doing written assignments or listening to the teacher, and Bridget talks about labwork activities being necessary for verifying their theoretical knowledge. In relation to the report writing, they perceive it as the time where they truly understand their work in the lab, and as very good notes for later studies. Brit talks about reports as a test to see if you understood the physics subject.

Later they talk about the specific labwork of conservation of mechanical energy, when asked to describe the labwork:

LBJ *Try to describe the experiment to me.*

Brit Then you even got to remember [laughing].

Bridget It is how the kinetic energy is like horizontal and the potential energy is going down. It is like the way I... Or it becomes less. It is the one becoming negative. And our kinetic energy pulling it horizontally. Right? And then we have like... it is made on an air track - I guess to prevent friction. So we do not have to include it.

As seen, it is very difficult to understand what Bridget means, indicating how it is unfamiliar for her even to use the concepts of friction, kinetic and potential energy, and thereby making her abilities to explain the labwork quite poor. They continue:

LBJ *How do you get information of the kinetic and potential energy from the experiment?*

Bridget Like how you calculate it?

LBJ *How do you indirectly measure it?*

Bridget It is like the kinetic energy that is minus our mass of what was it? It was the pull weight, right? The mass of the weight minus because it moved downwards instead of upwards. And then we have the gravity or what is its name, gravitational force. And what was the last. It was...

Brit It was a half.

Bridget No it was the distance, how far it drove on this. Kinetic energy. You could say the speed was interrupted of, or before it was measured. Or was it only the distance?

233 **Brit** Yes, it was the thing, what was the name. . . ?
234 **Bridget** The flag.
235 **Brit** The flag? No, now we are talking about two different things.
236 **Bridget** Then what are you talking about?
237 **Brit** The measurer.
238 **Bridget** Oh, that sensor.

Here they are trying to clarify the role of the kinetic and potential energy in relation to the setup and their measurements, but turn towards having problems deciding what the counter attached to the photo cell actually measured:

240 **LBJ** *What did you measure with it?*
241 **Brit** We measured. . . it could. . . because it got sent through. . . what was that
242 got sent through?
243 **Bridget** The flag.
244 **Brit** No, it wasn't that which got sent through? It was light. And when the
245 flag stopped it, so it got blocked, and then it stopped the time and the
246 distance.
247 **Bridget** Over a very short distance it measures the velocity or what is it called,
248 well how long it was interrupted in this piece which the flag is. And you
249 need it over a very short time to measure it, because if it was for a longer
250 period it would accelerate all the time. So it is crucial to measure in a
251 very short period or. . .
252 **LBJ** *What do you use it for?*
253 **Bridget** It was for the kinetic energy, as far as I remember. No.
254 **Brianna** Yes.
255 **Bridget** Yes. The kinetic energy is like. . .
256 **LBJ** *Is the time displayed anywhere in the equation for the kinetic or potential*
257 *energy?*
258 **Bridget** What did you say? Say it again.
259 **LBJ** *There is no time in any of the equations?*
260 **Bridget** No, but time is used to calculate the speed. So you can. . . To find out
261 how fast it moved on this place.

Finally the students agree upon the sensor is measuring the speed at the place of the photo cell, but never gets around to describe the labwork and its official aim in clear sentences. Earlier in the interview they stated how they are not really ready to give any answers to the official aim of the labwork, since they have not yet done the calculations:

191 **Bridget** Now we haven't worked with it very deep yet. We have just calculated
192 on those energies. And seen it as, it becomes the same, it is almost the
193 same, so we have the mechanical energy.
194 **Brianna** It is good to have it included.

Later in the interview the students were asked about Burt's intentions with the labwork in relation to their learning.

337 **LBJ** *What do you think Burt meant you to learn from this labwork?*
338 **Bridget** Yes, briefly it is about kinetic and potential energy and how it works;
339 how the masses and the like affect it. And then the thing about standing
340 with it on your own. [Quietness and giggling] Do you have anything to
341 add? [More giggling and quietness]

After probing several times for discussions of more general understandings without putting answers in their mouths, the question was left behind.

Brianna, Bridget and Brit find labwork activities relevant for the learning of physics. Apparently they have problems understanding the design of the labwork and how it relates to their theoretical knowledge. They are not able to discuss the labwork in relation to its learning potentials, which might not be surprising, since it is something Burt has not discussed with the students or written in the labguide.

8.4.4 Bob, Bonnie and Bobbi

One interview was done with Bob, Bonnie and Bobbi just after the labwork activity. The interview guide can be found in appendix B, and besides focusing on their educational choices, their expected future educational choices and their perception of physics and physics education, the interview focuses on the specific labwork in play concerning mechanical energy.

In relation to their plans for further studies, Bobbi intent to study mechanical or electrical engineer. Bob considers becoming a vet, and Bonnie is not having any plans by now.

During the interview the battery runs out of power, so sadly a part of the interview was not recorded. Therefore the students' answers to the question about Burt's intentions were not recorded.

When asked whether they find it important to be skilled in the student laboratory, the students answer:

98 **Bobbi** Well.
99 **Bonnie** Or not like being good, because, well. It is just that about change
100 a quantity for real. Oh, it behaves like that. You get another kind of
101 understanding when seeing it in real. And it is also more fun.
102 **Bobbi** It is also more fun to calculate on your own results. Well, instead of
103 being given some.
104 **Bonnie** And writing a report on the basis of it.

Bonnie describes how being skilled in the laboratory is not really important, the labwork is an activity for experiencing phenomena, being able to vary quantities and thereby manipulating the phenomenon in play, and finally to have fun.

The students are then asked about their feelings about doing labwork activities:

LBJ *How do you feel about doing labwork activities?*

Bobbi It is fun. It is nice, like PE[3] can be nice because it is a change compared to sitting in a chair and looking at the blackboard. It is also because you gain - like Bonnie just said - you get an understanding of what it really is. Because one thing is to be told the speed times that gives that... it is more fun to see, oh okay, speed and distance. Then we are standing there and measuring and time and such. Okay, I can see how it is becoming that way. It is easier to understand, when you yourself have ...

Bonnie And especially - like Bobbi said - it is also fun to use the work you have done yourself to base you writing on afterwards compared to be given it.

As Burt, Bobbi talks about varying the teaching from more still activities. Also she perceives the hands-on as important for understanding the physical concepts in play. Finally it is a good entrance for doing calculations and data handling, which she emphasizes as important.

Finally the students are asked about their perceptions of the report writing:

LBJ *What about report writing?*

Bob It is fine by me.

Bobbi You kind of collects it all, you get it under control in the end. I think.

Bonnie Yes. And now here we get a very thorough description of what to include, and that makes it easier. But also, how you get things clarified. If there is something in the ordinary teaching you haven't quite grasped, it shows in the report. Well, yes, what does this really mean? Or you get around asking about it, because else you can't write about it. Or you get corrections in the report, right. So that sometimes ensures you can see, oh, this I didn't understand. And then you get it clarified by rewriting it.

Bob It is kind of a summary. You have some theory, and then you have the practical stuff, and then you collect it all in the report. It is where you really understand it.

Bonnie Yes, and you can put the practical and the theoretical together.

Bob Yes, it is on that basis you conclude.

The reports are both used as a way to collect and order all the knowledge, but also as a test on the students understanding and lacks thereof. To do this, Bonnie finds it important the labguides are written so thoroughly the report writing runs smoothly.

Later the students are asked to describe the labwork:

[3] Physical education, sports.

Bob Well, we had a track, an air track. And then we had a cart with a flag. No. . .

Bonnie And then we had to measure the time of the cart.

Bob Through the photo cell which we had. And then we measured how much time it took for the flag to drive through. And then we also had the pull weight in the other end which pulled it.

Bonnie To see how much it does, well, what we are to see is. . . how much. Well, we varied the distance and the mass of the pull weight, to see the effect it had on the velocity and our. . . Wasn't it also about the kinetic and potential energy? I think so.

Bob We figure it out when doing the report.

The students start out by explaining the apparatus. Bonnie includes a discussion of the measured time, and Bob picks up on this and discusses which quantities they varied. Finally Bonnie starts talking about kinetic and potential energy, but this is wiped out by Bob stating how that part of the labwork description can wait until the report writing. This idea about not considering the physics concepts during the labwork activity is taken up later:

LBJ *Do you think about the physical concepts which the labwork is about while doing it? Or are you busy with following the labguide?*

Bonnie I don't think about it.

Bob Not while doing it. I can do it while doing my report.

Bonnie Afterwards I think about it. Because while there I just need to make it work.

Bobbi Well, of course I think you reflect upon what it is. Because. If you get a result, how can that be? So somehow we thought about it when we got some wrong results. That can't be. So somehow you have thought about it.

Bonnie Yes, and therefore thoughts. We couldn't understand it got bigger, because I thought it was the velocity we measured, but then it was actually the time.

Bobbi So in one way or the other you think about it. Because else it goes totally wrong.

First they agree with Bob's statement about only focusing on getting through the labwork, but Bobbi includes how they have been discussing unexpected data during the labwork, and that proves they are reflecting upon their data and results while doing the labwork displayed in the teacher interview.

Sadly due to technicalities the students answers to the question about Burt's intentions with the labwork was not recorded, but their answers resembled Brianna, Brit and Bridget's in not really understanding the question, since the point of the labwork was to verify conservation of mechanical energy, as well as experiencing the relation between theory and practise.

Bobbi, Bob and Bonnie perceive labwork activities as important on relating theory to practice, to vary the teaching, to experience the phenomenon in play and to get a good argument for doing data handling. In this way their perception of the labwork activities are strongly correlated with Burt's unarticulated intended learning outcomes of the labwork.

8.4.5 Daisy, Dana and David

One interview was done with Daisy, Dana and David just after the second labwork activity concerning halfwidth. The interview guide can be found in appendix B, and besides focusing on their educational choices, their expected future educational choices and their perception of physics and physics education, the interview focuses on the specific labwork in play.

In relation to their plans for further studies, David considers studying medicine, Daisy hopes to be accepted on the school of journalism, and Dana has not decided yet.

During the interview the students were taking in an additional data series. Also there were some interruptions by other students, which wanted to use to room.

First the students are asked how they perceive labwork activities:

Dana It is fairly cool, like to get it spelled it out by doing experiments, where you can see it happening. Because when you read about it, it is like, 'I understand', but when you see it in action also, well, I just find it more cool.

Daisy Yes, like the thing with to relate to it in a critical way. Like the apple falling. Well, like that, do that, and let's see. Yes.

David Yes, it is very much about to laying you hand on it yourself.

They talk about being convinced of the knowledge displayed in the books, but more importantly about being allowed to juggle the concepts in another environment, and thereby getting the knowledge in two-ways.

Later they talk about labwork activities as a teaching variety:

Dana It is very nice for a change.

David It is actually kind of cosy.

Dana To do labwork activities instead of just sitting in class and calculating on exercises at the board, which of course also is good, but if it was only that it would be kind of . . .

David Yes, it is important to vary it all.

Dana It wouldn't be cool if it was labwork activities every day, or every module.

Daisy No.

David There also has to be some kind of theory behind, which is presented at

the board.
Daisy Yes, precisely. Also that.

David discusses how labwork activities every day would be problematic, since the labwork activities have to be linked to theory, which should be taught before the experiment.

Later they are asked about the report writing:

David It depends on the pressure you are under.
Daisy Yes.
David Well, I would say sometimes it is a killer, if you at the same time. . . cause we are both having math and chemistry, or at least I have chemistry on A-level also. [. . .]
Dana Well, it is always like when you have to pull yourself together, it is kind of, oi, I would rather lay in my bed, or something. But when you get around doing it, it always ends out being cosy, or what to say, and then maybe you understand better, because you have sat down and written it and like told yourself what is happening, and the like.

Obviously the students find they are under a large work pressure from their courses, but while doing lab reports they are gaining an enhanced understanding both of the labwork and the relevant content.

The students are then asked to describe the halftime labwork, which was done around three weeks before the interview:

Daisy We measured, what was it, wasn't it? Of Barium, Ba?
David I don't think it was [bad audio]
Daisy Didn't it say. . . ?
Dana Yes, Ba-137.
David Was it?
Daisy Yes, I think so.
David Well, I think that is what we have right now. I am pretty sure, actually.
Daisy Now? [. . .]
Daisy Well, eh. . .
Dana Yes, we measured the. . .
David Yes, we measured the halftime of a liquid pushed through something radioactive. And then we had to figure out how fast the radioactive stuff decayed.
Daisy Yes. And find the halftime of it.
Dana Yes, and find the decay constant also.
David Yes, exactly, that was it.
Daisy And we made a beautiful curve.
Dana Very beautiful.
David And very uncertain.

Daisy Yes.

During this excerpt the student's attention is clearly on the data they are taking in. They talk about the radioactive material Barium, and how they used the date to determine the halftime and the decay constant, which they extracted from a curve, which formed a coherent pattern ('beautiful curve').

The students are now asked what they were to learn from the halftime labwork:

Dana I guess to make us understand.

David To gain a better understanding, right. And what . . . that was what I wanted to say.

Daisy And generally about radioactive materials, and then see how those material changes all the time.

Dana So it isn't just written in the book, the thing with it decaying.

Daisy Yes.

David Exactly the thing about seeing it with your own eyes. That is like. . .

In this part of the interview the students describe how the labwork was designed to teach conceptual issues, both semantic ('better understand') and episodic ('seeing it with your own eyes'). They do not discuss any other intended learning outcomes of the task.

The students are then asked to describe the halfwidth labwork:

Dana But, we find out how many lead plates we need for the gamma rays to be reduced to half. Or - that was very complicated put. [Everybody laughs]

David Yes it was.

Dana It was again the halftime, but the halfwidth. It wasn't the halftime, but the halfwidth, that is what I am trying to say.

Daisy Yes, where we need to find out how many gamma - no - how many lead plates we need to stop the gamma rays. And then just to see the halftime [halfwidth], and then we just, yes, we thought we just needed to find the first halftime [halfwidth], but then we realized we just needed to continue.

LBJ *Why do you need to continue?*

Daisy I guess to see a tendency of continuation; that it doesn't just half at that place, but that is also happens the next time; that it doesn't suddenly get linear or that something happens.

Here the students are clearer on describing the labwork, probably since it is much clearer in their memory. They both describe it is measuring the halfwidth, but also about detecting similar patterns in different places of the data range, which is an extended understanding of the exponential curve.

Then the students discuss what Derek wanted them to learn from the task:

Dana I guess it was to make us understand that there actually exist something like lead, which can stop gamma radiation. Well, you always here about

radioactive decays, or trash it is called, which can affect the body and I don't know what.
Daisy Yes, you could be very ill.
Dana So to know there is something which could stop it, and . . . yes.
Daisy Yes.
David Mmh.
Dana But, yes, to give us an understanding within this subject.

Dana immediately turns towards the argument of societal use of knowledge, which was also the point of Charles for the same labwork, and the other students hesitatingly agree. Dana also uses the argument which they used for the halftime experiment about gaining conceptual understanding. After some probing it was not possible to make them talk about uncertainties, and the students are asked directly about it:

David I did not think about it that way, but I could see that there were something, like a focus point in, well, exactly, also because we needed to repeat the measurements again and again, because to. . .
Daisy Yes.
David . . . we couldn't make it fit.
Daisy Wasn't it what Derek talked about, that radioactive decays; I can't remember was it random or something?
David Yes.
Dana Yes, it is.
David That is also what we see, sometimes it goes totally crazy, and . . .
Daisy Yes. Precisely.
Dana Especially on the third measurement [laughs].
Daisy Always on the third measurement.
David Always on the third measurement. It really wouldn't. . .
Daisy It is a systematic error.
Dana We could say so.

Here David agrees that the focus point of the labwork concerned uncertainties, but did not relate this to the question posed. Again, Daisy tries out the concepts of both random and systematic uncertainties, and they discuss the terms in relation to their measurements.

Rather unexpectedly - when thinking about their many references to uncertainties during the labwork itself - the students were not able to replicate or rephrase Derek's intentions about uncertainties of the halfwidth labwork. The students perceived both labwork activities as being about reaching conceptual understanding.

Their understandings of the official aim of the labwork activities were also rather poor. It seems obvious when reading through the transcript how the students are unfocused during the interview, since they are taking in data and relate to them. When confronted with Derek's intentions, they are aware of them, but have not truly taking them in as their own.

8.4.6 Summary

The five groups have each been interviewed directly after the labwork activities (Derek's group only once after the second labwork).

The students discuss labwork as a way to gain conceptual knowledge (episodic and semantic), to make the theoretical concepts of physics trustable, to experience a different teaching style, and as a way to be forced into working with written physics in the report writing.

Both of Alice's two groups are aware of Alice's intentions with the activity, and are able to refer and discuss them in relation to the specific labwork if self. It seems they have taken Alice's intentions in and are perceiving them as their own learning purpose of the task.

Burt's two groups are not really grasping the question of learning purposes and are returning to the official aim.

The same thing is the case of Derek's group, which does not themselves name the learning purpose of systematic and random uncertainties. When confronted, David recognizes it as a special 'focus point' of the labwork, but besides this the students want to place the work of the purpose to the report writing.

Since the students have been accustomed with me during the labwork activities and as well as the previous lessons, and the fact that the interviews were done group wise, it seems the students are fairly secure during the interview situation, and reading through the transcripts several laughs and jokes are found.

It is obvious when comparing the interviews with the teachers and the students that the teachers are much more accustomed with talking (about physics, about learning, and just in general), and the students often difficult to understand, since they are not finishing their sentences or explaining their points.

8.5 Reports

Finally the students' reports are looked at to see how the students have responded to the labwork, and how they have solved the task of reporting it. Copies of the reports can be found in the transcript report.

8.5.1 Alice's students' reports

Alice has asked her students to hand in the report group wise in the groups in which they did the labwork activity. Therefore one could expect extra work has been put into the report.

Abby and Abraham

Already in the introduction Abraham and Abby address Alice's intention concerning *variable control*: "The aim of this report is to verify the equation of state by use of variable control. That means only two quantities are varied in each experiment, and thereby the connections, which the equation expresses, can be verified." (Report by Abraham and Abby, p. 2)

This issue of variable control is later taken up a number of times. First concerning the experiment of p as a function of V: "In the experiment only p and V are varied, and therefore $n \cdot R \cdot T$ is constant." (Report by Abraham and Abby, p. 4) and then for the experiment concerning p as a function of n the same phrase is used.

Later they write:

> The graph displays the pressure as a function of the amount of matter. This cannot be seen directly since the value on the x-axis is the volume. The volume does not display the volume at the measuring time but the volume of the air in the syringe before the volume is varied to the constant. This is the easiest way to change the amount of matter without changing any other variables, whereby variable control is done. The method can be used, since there is proportionality between the amount of matter and the volume: $n = \frac{V}{V_M}$.
>
> (Report by Abraham and Abby, p. 9)

and then for the experiment concerning V as a function of T: "In the experiment only T and V are varied, and therefore $\frac{n \cdot R}{p}$ is constant." (Report by Abraham and Abby, p. 11) and finally in the conclusion:

> In this series of experiments the connections of the equation of state have been verified by use of variable control. In experiment 0 and 3 the results are though not good enough to be directly used, opposed to both experiment 1 and 2 which shows excellent agreement between theory and experiment. Each experiment shows a certain connection, and when these connections are put together, the equation of state can be deduced.
>
> (Report by Abraham and Abby, p. 14)

These quotes show how Abraham and Alice have taken in the idea of variable control as a reasonable purpose of the labwork. Also the quotes show how their understanding of variable control is well developed.

Also, Abraham and Abby address Alice's purpose of *graphical data treatment*.

Besides using some time in the beginning of the report on the measuring units of the quantities in play and how they relate to the table value of the gas constant given in other units, for experiment 1, 2 and 3 the students spend some time on relating the data displayed graphically to the ideal gas law as well as the direct measurements of the constants. E.g. they write about the first experiment where the pressure is measured as a function of the volume:

> On the graph above is the pressure displayed as a function of the volume. [...] The equation of the fit function is a reciprocal proportionality
>
> $$f(V) = \frac{1,516kPa \cdot mL}{V}$$

> According to theory the number $1,516$ is equal to the constant $n \cdot R \cdot T$.
> (Report by Abraham and Abby, p. 6)

and for the third experiment concerning the volume as a function of temperature:

> Above is seen the volume as a function of the temperature. The equation of the fit function is
> $$f(t) = 0.002598\frac{mL}{\circ C} \cdot t + 0.4743mL$$
> The slope equals the constant $\frac{n \cdot R}{p}$.
> (Report by Abraham and Abby, p. 12)

As seen Abraham and Abby have a good understanding of transforming the fit function from a mathematics equation to a physics equation, and relating the fit constant to the measured constant, including unit conversion.

As seen from the above quotes, Abraham and Abby address both of Alice's intended learning outcomes (besides her direct purpose of learning about the equation of state, which obviously is addressed in the report). They address Alice's purposes in a way which clearly indicate how they perceive the purposes as important in order to report the labwork and the recorded data, and they have a high level of understanding of the purposes.

Also the students address other issues in the report, such as they discuss how the results of the three experiments can be used to deduce the ideal gas law. Also Abraham and Abby discuss percent wise uncertainties and relate them to the sources of errors, as well as patterns, variable identification, etc.

Anita and Annie

Anita and Annie refer to Alice's purpose of *variable control*, but opposed to Abraham and Abby, they are not directly discussing the official aim of the experiments by referring to variable control. Instead they write e.g. for the first experiment: "Aim: To investigate if the connection between the pressure (p) and the volume (V) fits to the equation of state for an ideal gas." (Report by Anita and Annie, p. 1)

For the other two experiments, the same phrase is used with different quantities for the independent and dependent variables.

First time they refer to variable control is in their section about theory, and it is in a less pronounced way than was the case of Abby and Abraham. Again for experiment 1: "The equation of state is $pV = nRT$. Already now it is seen how p and V are reciprocal, but we still rewrite the equation to: $p = \frac{RnT}{V}$. RnT is a constant." (Report by Anita and Annie, p. 2)

They are not discussing why RnT is constant, but simply state how that is the case.

Concerning the third experiment they address variable control more direct by stating: "Since we in this experiment want to show V as a function of T the rest needs to be constant, wherefore $\frac{Rn}{p} = constant$." (Report by Anita and Annie, p. 5)

Anita and Annie do not use the term of variable control in their report, and it seems they are not as familiar with the term and its understanding as was the case of Abraham and Abby. Still the quotes show how they understand the need of controlling the other variables in order to see the connection between the independent and dependent variable in play.

Also Alice's purpose of *graphical data treatment* is addressed in the report by Annie and Anita.

For the first experiment concerning p as a function of V they write:

> From the section about theory we expect p to be reciprocal to V: $p = \frac{RnT}{V}$, which we have confirmed, since the measuring points are placed along a line with the equation $y = \frac{A}{V}$ where $y = p$ and $A = RnT$. There are though systematic deviations. From theory we also know that RnT is a constant, and we can calculate its value to see if it fits with the graph.
>
> (Report by Anita and Annie, p. 3)

They then calculate the value of RnT by use of some unit conversion and end out by finding the percent wise deviation from the graphical result and the direct measurements.

Generally, the students are not as certain as the previous group, but they manage in their own words to describe how they translate the mathematical fit expression to a physical equation and relate the fit coefficient to the direct measurement.

In the other two experiments, the students use the same strategy to explain their findings, but do not discuss Alice's ideas about graphical data treatment to a higher extent.

Based on these excerpts it is apparent how the students accept and understand Alice's purposes as relevant to the labwork, and how they come a long way on understanding them. Still they have some issues with them and have not moved as long as Abraham and Abby.

Besides addressing Alice's aims of variable control and data treatment, the students also discuss some additional issues. A number of times the students use the concept of systematic deviations, but it seems they are not really grasping the term.

Also the students in experiment 3 concerning V as a function of T discuss why the fit value b in the fit function $y = ax + b$ deviates from the expected value based on their knowledge of the absolute zero temperature. They end out by concluding (especially for the third experiment) how the comparison between the measured value of the constant variables and the derived value based on the fit of the graph corresponds very poorly, but still something can be said about the connection between the independent and dependent variable.

Opposed to Abby and Abraham, the discussion of the additional volume in the pressure meter and its effect on the data is not really addressed. It is mentioned, but merely as a reference to the labguide and not displaying a real understanding.

Experiment 2 and the change between the independent variable (the amount of matter) and the measured volume causes some discussions, which shows how the students have grasped this idea of direct and indirect measurements.

8.5.2 Burt's students' reports

As Burt did not put forward as clearly as Alice his intentions of the labwork, and therefore the analysis of the report is not done by searching through it to find evidence of the students' level of understanding on the purposes put forward by the teacher. Still, by use of the work done in chapter 5 interesting things can be said about the students' learning and understanding in relation to the lab report.

Burt's students hand in individual reports, and all of the reports are significantly shorter than was the case of Alice's students. This resembles the fact that the labwork itself also was significantly shorter and the data handling demands less time as well as space.

Each of the lab reports typically contains a description of the labwork and possibly a picture or sketch of the setup, a section containing a description of the theory, a section with data handling in form of a scheme and a detailed description of one of the calculations, a section about sources of errors and a conclusion, as was also listed in the labguide. The first couple of sections are typically rewrites of the labguide, and the data handling are done on the basis of the scheme of the labguide.

Brianna

Brianna hands in a report showing first a description of the setup and a section about theory, which is more or less identical to that found in the labguide. She does not give an aim of the task. Then she fills out the in the labguide given scheme in order to gain values of the change in kinetic and potential energy. First in the section about sources of errors she displays something not directly dictated by the labguide in stating four sources of error, but with no discussion of the effect those will have on the data. In the conclusion she puts forward how the percent wise deviation (of the difference between the kinetic and potential energy related to the potential energy) increases with an increased weight of the cart, indicating higher friction for a heavier mass: "From the scheme at page 3 you could conclude the percent wise deviation increases significantly when the weight of the 'car' is doubled. This makes sense, since the friction of a heavier mass is larger than the friction of a less heavy one." (Report by Brianna, p. 4)

No similar conclusions are though drawn for the other things varied (the position of the photo cell and the weight of the pull weight). Also no discussion is given of the sign of the deviation; that is whether the percent wise deviation indicates a too high value of the kinetic or the potential energy compared to the theoretically expected.

According to the comments by the teacher, this report lacks a further discussion of the sources of errors and conclusions, but otherwise fine, and is graded to a 10, which is the second to largest grade on a seven scale grading system.

Bridget

Bridget also hands in a report. She starts by stating the aim of the labwork activity as: "Aim: Our aim is to investigate the transformation between potential and kinetic energy in a motion on an air track. This is done to find out if the mechanical energy is conserved." (Report by Bridget, p. 1)

She then draws a sketch of the setup and prints a filled out scheme of the data and the data handling, though not displaying the percent wise deviation. By use of the theory given in the labguide she provides the reader with an example of her data handling.

At the next page Bridget discusses the results. Since she does not calculate the percent wise deviation she discusses the conservation of mechanical energy on the basis of the difference between the measured value of the kinetic and potential energy, though not displaying any discussion of which is larger than the other. In the same way the discussion of the sources of error does not display how they affect the data.

Bridget also discusses the data set where the mass of the cart is doubled, and how the data deviate more than the other data sets. She discusses that this is the case, but not why this is a result of the increased weight.

Finally she concludes:

> We have now tried in practise to verify the transformation between potential and kinetic energy. This we did on an air track to - in theory - remove the friction. In this way we could measure and find out if the mechanical energy is conserved. It was then shown that the mechanical energy is conserved with on exception.
>
> (Report by Bridget, p. 2)

The comments by the teacher are positive, though asking for a percent wise calculation of the deviation. The grade is 10-12, where 12 is the highest possible grade.

Brit

Brit has in her report stated how she perceives the aim of the labwork activity: "Aim: To conserve the mechanical energy." (Report by Brit, p. 2), which can be interpreted as either humorous or truly lacking any understanding of the purpose of the labwork activity.

The lab report continues with a sketch of the setup and the filled out measuring and data handling scheme, though without percent wise deviations. An example of the calculations is given. Calculating $\Delta E_{pot} + \Delta E_{kin}$ shows how they are all negative, which she emphasises, and are all close to zero besides the last experiment (with a large cart weight): "All results lie below zero, they are all fairly close to 0 except the 6th which is further away. The mechanical energy is conserved the best in 1-5. " (Report by Brit, p. 3)

She does not give any hypotheses of why this is the cases, and in her section about sources of errors she emphasises inaccuracy as the main source of error.

Burt's comments to the lab report are that the report lacks a further discussion of sources of errors and comments on results. The grade is 7 (third highest grade on the seven scale grading system).

Bob

Bob initially states his aim of the labwork: "Aim: Investigation of the transformation between potential and kinetic energy by a motion on an air track." (Report by Bob, p. 1), which is very close to the phrasing in the labguide. He then draws the setup and displays the measured and calculated numbers in the data scheme. He discuss the value of $\Delta E_{pot} + \Delta E_{kin}$ in the following way:

> ΔE_{pot} and ΔE_{kin} are compared by adding the two values (the column furthest to the right). If the mechanical energy is conserved the result will be 0. In none of the experiments the result is 0. In all experiments the growth is negative; that is some of the mechanical energy in converted. This can be explained by the sources of error, since the mechanical energy is only constant in the case of no friction and no air resistance. In the experiment an air track is used to reduce the friction, but there might still be some friction. Also there is some friction in the pulley. Also the air resistance can affect the results. These factors can "decelerate" the cart and some of the mechanical energy can be converted to heat (intern energy), which could cause uncertainties in the results.
>
> (Report by Bob, p. 2)

As the first one he discuss the sign of found value of $\Delta E_{pot} + \Delta E_{kin}$, and explains this in relation to some of the sources of error.

He then calculates the percent wise deviation and lists the sources of error. In the conclusion he again discusses the effect of friction and air resistance as well as the uncertainty that lies within the size of the flag.

Burt comments on two calculation errors, but otherwise calls it 'good' and grades it 12.

Bonnie

Bonnie starts her report by stating the aim: "Aim: To investigate the transformation between potential energy and kinetic energy by a motion on an air track." (Report by Bonnie, p. 1) which is almost identical to the aim of the labguide. She continues with a sketch of the setup and a filled out measuring scheme and a data handling scheme. She explains her results by:

> If the mechanical energy were to be conserved in the experiment it should have been equal to zero. In theory our results for the mechanical energy should then have been 0, because we know for the case of no friction the mechanical energy is constant (the air track makes sure there is no friction). For all of our results for the mechanical energy the growth is negative; that is some of the mechanical energy is transformed. This can be explained by the sources of error.
>
> (Report by Bonnie, p. 2)

She then calculates the percent wise difference, but does not comment on it. She lists a number of sources of error and explain how they can affect the results, but not in which direction. She ends out by stating: “Some of the named factors have been able to “decelerate” the cart and thereby some of the mechanical energy could be converted to heat (inner energy).” (Report by Bonnie, p. 3)

In the conclusion she states how the labwork have been able to verify conservation of mechanical energy to some extent, and the deviations can be explained from the sources of error.

Burt gives the grade 10-12 and has added no comments.

Bobbi

Also Bobbi states the aim of the labwork by: “Aim: The aim of this labwork is to investigate the transformation between potential and kinetic energy by motion on an air track.” (Report by Bobbi, p. 1)

A sketch of the setup is given as well as a short description of the apparatus used. The measuring scheme is filled out and an example of the calculations for the data handling is given, followed by a data handling scheme.

She comments her results in the following way:

> Energy does not disappear; it can be transformed into something else, but it does not disappear. Potential energy is converted to kinetic energy when an object starts to move. Therefore should ΔE_{pot} and ΔE_{kin} have the same size and opposite signs. Comparing ΔE_{kin} and ΔE_{pot} from the schemes it is seen that none of the results have the same value with different signs.
>
> (Report by Bobbi, p. 2)

She explains the percent wise deviations by wrong measurements, moving the flag or friction. She concludes rather vaguely that patterns are seen, and interprets that as potential energy is converted to kinetic energy during the motion.

Burt comments on her conclusion by stating the patterns indicate that approximately 20% of the potential energy is converted to heat, and he grades it to a 10.

General

When reading through the lab reports and reading Burt’s comments, it resembles Burt’s previous statements about the labwork in the sense the students are using the concepts of mechanical, kinetic and potential energy as well as doing some data handling which have already been established in the labguide. Burt asks for a percent wise deviation calculations, but it seems the students do not really understand why.

The discussion of the sources of errors is acceptable if they are listed and described, but Burt is not preparing the ground for discussions of their effect on the results. The second group seems to have a higher understanding of the effects which the sources of error cause on the data than the first group.

Comparing the students lab reports to the analysis of the sub-skills of the procedural domain, which is addressed or could be addressed according to the labguide, some comments should be made.

In relation to *variable identification*, *fair test* and *variable types*, none of the students comments on these factors. This was not directly addressed in the labguide, but could be - as discussed earlier - relevant for the labwork.

The students only vaguely discuss *choice of instrument* when talking about sources of error, especially in relation to friction, air resistance, horizontality of the air track and choice of flag. *Relative scale* is as expected not discussed, since the possible choices of pull and cart weights give relevant limits.

Tables are of course done by all students, but are not discussed, since the students fill out the pre-printed scheme. *Patterns* are discussed by Bob, Bonnie and Bobbi when discussing the sign of ΔE_{mec}. *Units* does not seem to cause any issues.

All students discuss *uncertainties and errors* as well as *reliability*, but on very different levels, where some merely list sources of errors, and others discuss their effect. Still, the discussion only gets this far and could be unfolded even further.

8.5.3 Derek's students' reports - halftime

The same group of three students was followed for the two labwork activities of the halftime and the halfwidth by Derek.

For the halftime labwork, the labguide and Derek's introduction were deliberately designed in order not to give any clues of the intended learning outcomes of the labwork, whereas the halfwidth labwork was designed to make the students focus on uncertainties (random and systematic).

Daisy's halftime report

Daisy introduces her labguide by stating the official aim of the labwork as "The aim of the labwork is to determine the intensity of the background radiation I_{backgr} and then determine the halftime for $Ba - 137^*$." (Report by Daisy, p. 1) This is more or less identical to the phrasing in the labguide.

After having given a list of materials and apparatus as well as a description of the labwork, she continues on with a quite long section about theory, where she describes isotopes, radioactivity as a transformation towards the lowest energy state, alpha-, beta- and gamma-radiation, background radiation, and the decay formula.

This is followed by a section concerning results, where she gives the found value of the background radiation based on an average over 3 minutes. She then displays the data for Barium including a graph with an exponential regression. Further discussion of the data displayed in the graph, the patterns and how they differ from the regression are not discussed. The fit function gives a value of the decay constant, which cause a value of the halftime. The percent wise deviation from the table value is found to have the value 29.2131%.

The fairly large deviation is explained in the section about sources of error:

> Our fairly large percent wise deviation is probably caused by the source of error which is that we were the last group to use the mini generator, and therefore the amount of Caesium nuclei left is low, which results in our radioactive liquid does not contain a lot of daughter nuclei $Ba - 137^*$, and therefore there will not be the largest activity.
> Another source of error is that we were to slow between our measurements where the GM counter were not counting and in the period between the GM counter stops till we start it again some nuclei can decay and these will not be part of our calculations. Therefore it can cause a lower results and our large deviation from the table value.
> A source of error is that radioactive materials decay randomly, and therefore the experiment must be repeated many times for it to give what is most likely correct.
>
> (Report by Daisy, p. 5)

As seen Daisy is aware of the fact that their slowness during their data measurements will cause a measured halftime, which is too short. The other two sources of error which she lists do not really explain the large deviation, though she expects so.

Dana's halftime report

Dana gives the official aim of the labwork to be: "The aim of this experiment is first to determine the background radiation and then determine the halftime of $Ba - 137^*$." (Report by Dana, p. 1)

As Daisy, also Dana has done sections about background knowledge called 'theory', 'radioactive decays' and 'decay law', where she explains the radiation process of the labwork, alpha, beta and gamma radiation, as well as the decay law. She then describes the labwork activity and displays a material and apparatus list.

This is followed by a section about the results. First the background radiation average is given, and it is explained how this value is subtracted for the following data for Barium. The data are then displayed in a graph and an exponential regression is done. The graph is commented in the following way:

> As seen by the above table it was very random how many rays the GM-tube detected. Including the thing with the average background radiation we measured, our calculations can not be completely correct, which is also seen in the below calculations.
>
> (Report by Dana, p. 4)

She tries to explain how come the data are not following the regression formula completely by expressing the randomness of radioactive measurements, though being fairly vague in her formulations.

She then calculates the halftime on the basis of the fit equation and determines the percent wise deviation.

She again comments on the random nature of radioactivity:

> As previously mentioned it totally random how many rays were detected, since we have our radioactive material in front of the Geiger-Muller tube. Since it was also an average background radiation we calculated it can of course not be completely precise.
>
> (Report by Dana, p. 4)

It seems rather peculiar that she states it is totally random how many rays are detected, and then afterwards with full comfort fit it to an exponential function without further comments. It is not clear what she means by it besides emphasizing some uncertainties are expected in the data.

As Daisy, she also comments on the period between measurements and its affect on the found halftime value:

> While we used time to reset our counter while measuring when our substrate was below the Geiger-Muller tube the substrate was decaying at the same time since the substrate does not stop decaying while we reset. Since we by use of a stopwatch in a mobile phone noticed radiation pr. 10 seconds a source of error could be that we were either too fast or too slow to start and stop the watch.
>
> (Report by Dana, p. 5)

Again it is not completely clear what she means. It seems she expects them to be able to restart the counter 'too fast', which is physically not possible. Also, she has no comments on whether it will draw the halftime towards too low or too high values.

David's halftime report

David states his official aim of the labwork to be: "The aim of the labwork is to determine the background radiation in a specific cup which we call I_{cup}, and determine the halftime for $Ba - 137$." (Report by David, p. 1)

This emphasis on the cup might seem rather weird, but it is probably his way of saying he placed care in measuring the background radiation under the exact same circumstances as for the halftime experiment, just without the radioactive substrate.

As was also the case of Daisy and Dana, David spends some time explaining what he calls 'theory', which is a description like those found in a school book about radioactivity, decays, decay constants, etc. This is followed by a list for materials and apparatus and a description of the labwork.

In the section names 'result handling' he gives their background radiation average value as well as the table and a graph of the halftime data. An exponential regression is done, and the found fit equation gives the decay constant and then the halftime. Further discussion of the data displayed in the graph, the patterns and how they differ from the regression is not discussed. The percent wise deviation is found. So far the data and results have not been discussed.

As a conclusion he states:

> We can conclude that the background radiation in an average measuring cup is approximately 1.9444 pr. seconds, and that $Ba - 137$ has a halftime of 108.304 seconds, which does not resemblances with what other data books tells, and therefore there must be sources of error, probably because of the small pause between each measurements and that the material in this period was not measured on.
>
> (Report by David, p. 4)

As Daisy, also David discusses the period between measurements where no data was taking, and that this will affect the halftime, but opposed to Daisy he does not discuss which direction such an error will draw the halftime value.

Generally

Comparing this to the discussion of the potential learning outcomes for the labwork based on the labguide, the students address some and leave other behind.

Variable identification and *variable types* are not discussed by neither of the students. The labguide leaves it as a possibility, but are not addressing it directly.

Relative scale is touched upon by Daisy when discussing the low activity, not due to the placement of the GM-tube, but by the students being the last ones to use the mini-generator. None of the students addressed *repeatability* in relation to the background radiation, but all seem to comment on the randomness of radioactivity decays, and therefore have implicit ideas of the problems with repeatability.

All students make tables and graphs (*tables* and *graph types*), but no comments are given on it. Only Dana comments on the *patterns* of the graph. *Units* seems not to be an issue for neither of the students. *Equation translation* is done by all of the students without any further comments.

Uncertainties and errors is discussed by all students, and they all draw forward the pause between measurements where the substrate keeps radiating without measuring. Daisy seems to know which direction it draws the data, but at the same time names other sources of error, which she expect to have the same affect without any reflections. Dana and David simply explain it as a source of error without reflection on its affect on the halftime.

8.5.4 Derek's students' reports - halfwidth

The same group of Derek's three students was followed for the second labwork of the halfwidth.

For the halfwidth labwork, the labguide and Derek's introduction were deliberately designed to make the students focus on random and systematic uncertainties.

Daisy's halfwidth report

Daisy states her official aim of the labwork in her report to be: "The aim of the labwork is to determine the background radiation N_{backgr} [and] the width of lead needed to half the γ radiation from Barium 137*." (Report by Daisy, p. 1) She probably expects the gamma source to be of $Ba - 137^*$, since the previous labwork concerning the halftime of $Ba - 137^*$ also dealt with gamma radiation.

The report continues on with a list of material and apparatus and a description of the labwork.

As was also the case of the halftime report, she spends some time giving a description of radioactive atoms, radiation types (alpha, beta and gamma), ionizing radiation, GM-tubes, gamma radiations and finally the decay formula for halfwidth.

As the previous report, she gives the background radiation as the found average without discussing the type of values it took. The taken data is displayed in a table with the background radiation subtracted, and is again displayed in a graphical form with an exponential regression. Based on the fit function the halfwidth is calculated and compared percent wise to the table value (their found value is higher than the table value by approx. 9%.

She spends quite some time discussing uncertainties and their relation to systematic and random uncertainties:

> The labwork holds different types of uncertainties which affect the found results. These uncertainties are random and systematic uncertainties. Th random uncertainties are those which only affect some data and these uncertainties are difficult to control. The widths of the plates and their shapes, e.g. if the plates are bend. This causes air between the plates, and it would be a random uncertainty, since the plate maybe will be placed as the last plate and therefore only will affect the last result. On the other hand there can also be systematic uncertainties which mean it will affect all data, if the bend plate is places as the first and in this way give rise to an uncertainty throughout the entire experiment.
> Another systematic uncertainty in the labwork is the spread of the gamma radiation. The gamma source does not only shoot rays in one direction but all the way around the source, like a circle.
> Therefore it will be a systematic uncertainty that not all of the decays from the gamma source will be detected by the source [GM-tube?].
> On the other hand it is a random uncertainty that the gamma decays happen random.
> A systematic uncertainty can also be our GM-counter. If this has a max. number of measures pr. second, and therefore cannot keep up, the radiation will therefore

> be lower than it really is. This will - if the intensity of the decays is way too high compared to the measurer - give us a graph that is almost linear [constant?] until our measurer again can keep up and it will then decay exponential. This is probably not the case since our graph is not linear but exponentially decreasing.
> A systematic uncertain could be that the lead plates are less than $1mm$, this will give us a higher halfwidth than the table value.
> There could also be some systematic and random uncertainties which even out each other and therefore will not change our result.
>
> (Report by Daisy, p. 5)

As seen, she has a fairly good understanding of random and systematic uncertainties, and has for some of the cases been able to discuss which direction such an uncertainty will pull the found value of the halfwidth. Also she gets around a large number of possible uncertainties, which she is able to categorize as either random or systematic.

She finishes out with a conclusion, stating that it has been possible to measure a halfwidth of lead for gamma radiation.

Daisy has taken in the ideas of random and systematic uncertainties and is discussing them directly in relation to the labwork, such as it was intended.

Dana's halfwidth report

Dana states her official aim of the labwork to be: "The aim of the labwork is to determine the number of lead plates needed to determine the halfwidth of gamma rays." (Report by Dana, p. 1)

As also Daisy (and her previous report concerning halftime), she starts out with a 'theory' section describing radioactive radiation. Here she discusses background radiation, chemotherapy, cosmic radiation etc. She also discusses weakening of radiation by use of absorbing materials, and describes the decay formula for halfwidths.

This is followed by a description of the labwork procedure and a material and apparatus list.

As was the case of Daisy she gives the found average counts of the background radiation, and display a graph of the halfwidth data with the background radiation subtracted. The data is also displayed graphically, and an exponential regression is done with a printed fit formula. From this she calculates the halfwidth and the percent wise deviation from the table value.

As Daisy, Dana also spend quite some space on random and systematic uncertainties:

> Sources of error is something which can occur more or less for every experiment, and these sources of error can be placed in two categories: the *systematic sources of error* and the *random sources of error*.
> *Systematic sources of error* are something which is constant throughout the entire experiment. It will then not be fluctuating deviations in the results you would get, since the same error will be there throughout the entire work. A systematic source of error would be if there was an error in the used apparatus, such

> as a weight measuring an objects mass to e.g. 2 grams more than the original. If you were to do an experiment where more objects needed to be weighed then the relation between the masses would continue being proportional, since they would all would be 2 grams heavier.
> In our experiment a systematic error would be if our GM-tube was to far from the source; this is though not as important since we used gamma radiation, which is a very powerful and energetic ray. If it instead would have been alpha radiation it would have affected the results more, since alpha radiation more easily can be stopped. There would then be a much lower number of radiations being registered by the GM-tube.
> Another systematic error would be if there was an error in our apparatus, but since we did not have any opportunity to investigate it, it is not that relevant.
> *Random sources of error* are the opposite of the systematic. Where systematic sources of error affect *all* data, it is only some random data that will be affected. Random sources of error are then uncontrollable. To avoid random errors one needs to repeat the experiment several times and then calculate an average. Another way of avoiding random errors is by doing your experiment in a controlled environment, and in that way avoiding various factors, e.g. air resistance.
> In our experiment there were most random errors, since it is radioactive decays we are handling. We do not know how much our source decays and when it will happen. Since our source not only emits radiation in one direction, but takes the shape of a sphere it will be random how many rays the GM-tube will catch.
> The lead plates we used to stop the gamma radiation might not have been exactly 1 mm in width, such as we are expecting. Since lead is soft and easy to bend some of our plates might be deform and that can cause errors in our measurements.
>
> (Report by Dana, p. 3, original emphasis)

As seen, Dana uses many of the same arguments as Daisy, but she focuses more on describing random and systematic uncertainties (which she calls sources of error) in a more general way, and spends less time on discussing it in relation to the specific labwork. She has some comments of how to avoid random uncertainties, which Daisy did not have.

She finishes up with a conclusion, stating the labwork has been successful.

As seen, Dana has taken in the task of discussing random and systematic uncertainties for this labwork, though with a slightly more general approach than Daisy.

David's halfwidth report

David states his official aim to be: "To investigate how many millimetre lead plates there are needed to half the intensity of γ radiation from Barium-137, and to shed light on systematic and random uncertainties of this labwork." (Report by David, p. 1) David draws forward the concept of uncertainty already in the aim of the labwork.

He continues with a descriptive section called 'theory', where he discuss alpha, beta and gamma radiation, their energies, its affect on a human body, background radiation and halfwidths, ending out with the decay formula.

This is followed by a description of the labwork and the needed apparatus.

For the data and the data handling, he as his two group members gives the average background radiation without discussion repeatability or uncertainties. He has a discussion of the choice between an exponential regression and a linear regression on a semilogarithmic graph. A table is given with the data, both with and without the background radiation subtracted. He displays both graphs and fits to both. He though runs into some issues in working with both a natural logarithm and a 10-logarithm, and therefore gets different results. He tries to solve his problem by reading out the halfwidth instead of using his fit for the semilogarithmic plot, but this of course does not save him.

As the two others, he spend some time on discussing sources of error in relation to systematic and random uncertainties:

> Systematic: There are quite a number of systematic sources of error for this labwork, the first we can see on the Geiger counter, there is namely a limitations on how fast it can count, so if the intensity is high it is impossible to count all, and then a change in the lead plates will not give a difference in the intensity, that is a measurement without lead plates in front and a measurement with $5mm$ lead plates would possible give the same intensity.
> Of course it is also important to keep the same distance from the gamma source to the Geiger counter during the entire experiment such that the photons have more or less the same track such that the same number of photons are missed during the entire course.
> Another systematic error could be to be inattentive and not using lead and instead nickel plates, e.g. since nickel and lead plates are placed in the same box.
> Random: A random error could be that Barium-137 of course does not decay constantly, which is the case when a nuclei decays. The chance of e.g. to play dice with 100 dices and not getting a single 6 exist - it is just very small. The same thing goes for radioactive sources, the chance of it decaying very little or not at all during the 10 seconds is there, and it is just very small. Therefore there exists a change for the data to be spread out and can jump a little in the intensity.
>
> (Report by David, pp. 6-7)

In his conclusion, besides commenting on his results, he again touch upon systematic uncertainties: "We have to focus on the sources of error, and what we could do to make our numbers more accurate, and here we especially has to look at the systematic, since it can fast give us wrong numbers for the entire experiment." (Report by David, p. 7)

As seen, also David accepts Derek's purpose of focusing on systematic and random uncertainties. He discusses some other errors than the other two when discussing nickel plates or not keeping the distance constant. When talking about random uncertainties he draw upon an 'experiment' the students have done previously with dices to give them a feel of randomness.

General

Generally, the students accept the purpose of understanding uncertainties for this specific labwork. Daisy and David discusses them in relation to the labwork, where Dana turns the discussion in a more general way. Especially Daisy is good at discussing which way the systematic uncertainties will pull the halfwidth.

There is obviously still something to be understood about random and systematic uncertainties for the students, but the general idea and how they play in on this specific labwork is somehow there.

8.5.5 Summary

For the reports by the students exposed to a high level of declaration, they are all taking in the teacher's purposes and are using them in the reports with fairly good results. It seems their understanding of variable control, graphical data treatment and systematic and random uncertainties (respectively) have been developed during the labwork activity and the report writing, and have now reached an acceptable level, though with room for improvements.

For the reports by the students exposed to a low level of declaration the reports shortly touch upon a few of the potential learning outcomes, but are never taken them very far.

What is also seen from looking at the reports is that the students operate with different 'report templates´, where e.g. Burt's groups focus on drawings of the setup, Derek's groups focus on long theory descriptions and lists of material and apparatus, and Alice's groups emphasize graphing.

Also the length of the reports are correlating closely with the period of time the labwork took; that is Alice's reports are very long, Derek's are about half the size, and Burt's are again half the size.

8.6 Summary and reflections

This part of the thesis (part IV) serves to answer the second research question: "*What is (if any) the impact on the students of a declaration of the teacher's intended learning outcomes of the specific labwork?*" As earlier discussed, the answer to such a question can by its nature never be evidential, but should be answered by a number of arguments summing up to a trustworthy result.

In this chapter the question is investigated by analysing four labwork cases. In part II the teachers' declaration levels of their intended learning outcomes were determined. Here focus has been on the students and how they react to the different declaration levels.

The four cases fall in different categories, which can be compared in different ways.

Alice and Burt are naturalistic cases in the sense that they are doing what they usually do and react to the activity and their students in a way that fall natural to them. They have very different ways of perceiving the learning purpose of doing labwork activities, both generally and for the specific labwork, which make them very interesting to compare. Alice is very clear on her intentions with the labwork and has specific learning goals related to physics for the labwork, which she presents to the students by different channels. Burt bases his labwork activities on teaching variety and affective arguments, and perceives labwork activities as a way to activate students into engaging in physics, but if they could be showing the same amount of work effort in other activities, they would be equally good. These very different perceptions of labwork and the fact that they display this difference very clearly in their introduction to the labwork serve as the perfect comparison cases for this sake. But on the other hand, the cases are as different as they could be: Different schools, different teachers, different students, different socioeconomic backgrounds, different topics, different labwork activities, different apparatus, different time intervals allotted to the labwork, different reporting demands. More or less the only things the two cases have in common are the school level and the physics level (second year, physics B).

Derek's two cases are an experiment on controlling the many variables, which there were no control of in comparing the naturalistic cases of Alice and Burt. By using the same teacher (and therefore same school, same students, and same socioeconomic background), and by demanding the same topic, same equipment, same time interval allotted, same reporting demands, and as close as possible the same labwork (it of course does not make sense to make the students repeat the same labwork for this sake and hope to get valid results from that), as many variables as possible are now controlled. Left is to make sure the two labwork activities have as different declaration levels as possible, and that gives rise to the problem that the teacher has to change his own practise (toning down the declaration level for one of the labwork activities and toning it up for the other). Therefore it does not come as natural to the teacher as was the case of Alice and Burt[4].

Different data sources have been analyzed in different ways. The data collected/done are video footage of the students' sayings and doings during the labwork, student interviews after the labwork activities and the handed in lab reports.

It is obvious to look for reactions in the students for the cases where the in-

[4] And the case of Charles proved it to be a larger issue than was expected.

tended learning outcomes are clearly declared (Alice's equation of state labwork and Derek's halfwidth labwork): That is looking at the transcripts, student interviews and reports for places where the students touch upon their teacher's intentions, and how they are taking this in, as well as understanding and developing it.

This strategy does of course not work for the cases where the intended learning outcome is not declared (Burt's mechanical energy conservation labwork and Derek's halftime labwork activities). Therefore the labguides are analyzed in order to find potential learning outcomes, as this was also done in section 6.4 for typical labwork activities in the Danish Gymnasium physics classes.

The analysis shows that the students *are* aware of the teacher's intentions when these are declared, whereas they are not able to explain learning goals for a labwork where the teacher has not declared his or her intended learning outcomes.

For the cases of a high level of declaration the students take up their teachers learning goals, try them out, use the words and phrases, and during the labwork they develop their understandings of them. All directly in relation to the labwork activity and labwork findings - that is it is not discussed in a general manner. During the interviews Alice's two groups are very aware of Alice's intentions with the labwork, whereas Derek's group is not. The entire interview though was affected by the students taking in data during the interview. In the lab reports the teachers' learning goals are also taken up and discussed (which maybe is not as surprising, since it is dictated by the labguide to do so). Also during the labwork and the reporting other relevant potential learning goals are taken up and developed, but not much emphasis has been placed on these.

For the cases with a low level of declaration the students are able to do the labwork activities, but the findings show their discussion of the labwork and their data and results are both quantitatively and qualitatively on a lower level. The interviews indicate the students are not able to discuss the labwork activity as a learning activity with a clear learning goal. It would probably also be too much to demand, when their teachers are not finding it important to do so. In the lab reports some of the potential learning outcomes are dealt with, again mostly when this is dictated by the labguide, and never on a very high taxonomical level.

When doing such an analysis I have tried to be fair towards both the cases with a high and a low level of declaration. It could easily be read into the made analysis choices that I was trying to prove what I already knew, and therefore deliberately or in-deliberately tried to manipulate the data. I cannot be sure it has not been the case (in the in-deliberate way), but I believe it to be an argument that the study started out with a very different view of labwork activities. Initially I sole wanted to prove that enquiry or discovery labwork activities are both possible and for the better, both in relation to students' interest and learning. Holding that view guided labwork activities like the cases here presented were more or less not able to teach students anything of value. The process of developing this study was then an iteration between what I read in the literature and what I experienced in the schools. Especially Alice and her awareness of her intentions with the labwork and how she explained this to her students along with the students' reactions to it became a great source of inspiration to the formation of the research project.

Being fair to all cases has dictated some of the choices I made in analysing the data. The quantitative analysis by use of the CBAV scheme is a way to look through the data and categorizing all actions and saying without focusing on specific learning goals. The data show that Alice's students and Derek's halfwidth students have a higher quantity of sayings displaying knowledge of how the experiment and the theory play together. When implementing the scheme, all sayings where the students ask questions, consider the labwork design, discuss the data, and wonder about the data treatment and result findings in a reflected way have been coded in KTP category. Therefore this category has significant overlaps with the metacognition category by Kung and Linder (2007). And being able to reflect upon the labwork, its data, findings and results most be valuable no matter which perception of labwork activities and their learning purposes one hold.

On the other hand, the CBAV scheme is difficult to handle. Whether one statement falls under one category or another is not unequivocal. I have tried to be consistent in all six data sets. The total numbers are not discusses; that is I have not discussed whether it is reasonable for a given category to fill out a specific percentage of the labwork time. The CBAV scheme is only used to compare the category levels of the six data sets, and by being consistent throughout the data analysis, the found data are trustworthy no matter whether another coder will code some statements slightly different. The question is then whether it can be trusted that the coding is consistent throughout the six data sets. Since this question can be posed, I emphasize the CBAV analysis should not stand alone, and the findings are supported by the other sources of data and their analysis. This triangulation proves as a validation of the data.

Finally I should comment that this analysis has deliberately not investigated the individual students. The students are perceived as an a unit, and their statements are addressed to the group and not the individuals. Therefore a lot more can be said on the background of investigating their action, statements and reporting by each of the students, but for case of this research question it is perceived as less important. Still I acknowledge that for most research questions focusing on individual students are crucial.

Part V

Closure

9 Conclusion

This chapter contains four sections, each dealing with the findings of this study. The first - section 9.1 - summarizes the research questions and answers. Section 9.2 discusses the findings, and investigates their trustworthiness, generality and importance. Section 9.3 discusses the arguments for asking and answering the questions, and finally section 9.4 contains a few personal comments, leading back to the personal motivation of the very first chapter.

9.1 Findings

In this section the research questions and research answers are summarized.

The two research questions are again:

1. *Which potential learning outcomes do the laboratory work activities commonly used in physics in the Danish Gymnasium hold?*
2. *What is (if any) the impact on the students of a declaration of the teacher's intended learning outcomes of the specific labwork?*

As this research study took place in an iterative process between reflections on research literature and curricula as well as pilot and case studies, the posing and answering of the research questions are obviously intertwined and have developed sideways. Therefore this summary does not necessary summarize the chronology of the study.

9.1.1 RQ1: Linking labwork activities and their potential learning outcomes

The first research question can be split into a number of sub-questions, where each are answered on the basis of the previous:

1. *Which potential learning outcomes exist for laboratory work in physics?*
2. *Which labwork types serve as their primarily purpose each of the found potential learning outcomes?*

3. *Which labwork activities are commonly used in physics in the Danish Gymnasium?*
4. *Which type of labwork activities are the commonly used labwork activities (and thereby which types of potential learning outcomes do they hold)?*
5. *Which specific purposes do the commonly used labwork activities hold?*

Which potential learning outcomes exist for laboratory work in physics?

To answer the first of the sub-questions a thorough research literature review was done in order to investigate which potential learning outcomes laboratory work activities hold. The research literature both included historical reviews of the school laboratories, studies of curricula, studies of teachers' and students' learning goals of labwork activities as well as researchers debating labwork activities.

Based on this work a sixfold categorization of purposes was developed: *conceptual domain, procedural skills domain, enquiry domain, nature of science domain, scientific attitudes domain*, and *affective domain*. Each of these purposes have been spoken for and against in the literature; that is each category could be understood in such a way that it has no validity from a learning perspective, but each of them could also be understood in such a way they are found completely valid for teaching students' relevant issues related to physics. It is what placed within the headline that defines its validity.

The *conceptual domain* should not be understood as labwork activities being an effective way of learning theoretical physics, which more obviously (and less problematic) could be taught by conceptual problem solving tasks. Instead the conceptual domain has valid links to labwork activities in their opportunities to provide the students with a long-term memory about a physical concept, both semantic but more importantly episodic.

The *procedural skills domain* could - based on Millar (1991) - be understood as a way to learn general cognitive processes (such as categorizing, observing, hypothesizing), a way to learn practical techniques (such as reading out scales, doing specific laboratory procedures, being aware of safety procedures in the lab) and a way to learn enquiry tactics (such as repeating measurements, drawing graphs to detect patterns in the data, identifying variables to be controlled, altered and measured). The first has issues on arguing why these general human skills can and should be taught in the school laboratories, and the second has the problems of transferability and relevance. The third, though, is a valid argument for doing labwork activities, and should be investigated into further details. Taking off from Gott and Duggan (1995), these enquiry tactics are investigated and categorized in five sub-skills: associated with design (variable identification, fair test, sample size and variable types), associated with measurements (relative scale, range and intervals, choice of equipment, repeatability, precision, random and systematic uncertainties), associated with data treatment (tables, types of graphs, patterns, multivariate data, units, equation translation), associated with evaluation (uncertainties and errors, validity, reliability), and associated with reporting (communication).

The *enquiry domain* is about learning to go through the entire empirical problem solving process. Again and again it has been discussed if students are able to solve such problems without relying on previously gained knowledge and skills. Woolnough and Allsop (1985) describe this process as taking the role of a problem-solving scientist, and argue for its immense potentials. A number of studies shows how this enquiry work is both beneficial, but also very difficult to manage.

The *nature of science domain* deals with understanding the grounds upon which physics (or science) stands. Millar (1998) talked about how physical phenomena are predictable and thereby serving something in an otherwise confusing world, on which the students can be confident. Wellington (1998a) and later Leach (2002) discuss the nature of science domain related to labwork activities to a higher extent, where Leach (2002) puts forward a number of hypotheses which students might wrongly or insufficient get about nature of science from doing labwork activities, but by that also indicates that being aware and open about it labwork activities can serve to give students a more sufficient understanding of the nature of science.

The *scientific attitudes domain* has often been put forward as a valid argument for labwork by stating how laboratory work in schools serve to develop valued attitudes, which scientists are expected to hold, such as e.g. curiosity, objectivity, perseverance and precision. Equally often it has been argued that these attitudes are not trained during labwork activities - and cannot by any reason be assigned to doing experimental work in a school setting. What seems to be less profound, but of much greater value in the discussions, is the students' experience of being able to approach a problem without an already given solution, and rely on own abilities to solve the task. This ability is of great value in all matters of life, and it *can* be trained when doing certain types of labwork activities.

The *affective domain* is problematic, since studies show diverging results as to whether students feel motivated, interested and satisfied when engaging in laboratory activities. A long list of factors seems to be influencing the students' affective perceptions of labwork activities, and these are not all controllable. It should though be emphasized that studies do show that labwork activities can evoke interest, and affective reasons should be a part of the considerations when designing labwork activities.

Which labwork types serve as their primarily purpose each of the found potential learning outcomes?

After having answered the first sub-question of the first research question: "*Which potential learning outcomes exist for laboratory work in physics?*", the work of this study turned towards answering the second sub-question: "*Which labwork types serve as their primarily purpose each of the found potential learning outcomes?*" To do so, six labwork types were recognized/developed, where each had one of the six learning goal categories as its primary purpose:

Experience is the labwork type developed to match the conceptual domain, and is a task designed for students only to grasp the phenomenon in play and talk about it, not to do any quantitative data collection and data treatment. Since in this type of labwork the students experience a physical phenomenon, which is obviously predictable (since the students can see the phenomenon happen more or less like the teacher intended it to happen), the students also could gain the part of the nature of science domain, which is related to predictability of natural phenomena.

Exercises are developed to serve the procedural skills domain; that is where the quantitative data collection and data treatment are of outermost importance. To do so this type of labwork typically is fairly guided, since the importance is for the students to gain data to work with. When focusing on the procedural skills domain, it seems unreasonable to expect the students to grasp parts of the scientific attitudes, enquiry or nature of science domains, though the students doing exercises might gain the episodic memory sought for in the conceptual domain.

Investigations are the labwork activities developed for the students to gain insight into inquiries - that is to be scientist (of some kind) when solving a very open problem. When doing so the students naturally works with all of the learning goal domains, but they will most likely not perceive them as the primary purpose of doing the task, and therefore one should not expect every secondary purpose to be met.

Meta-tasks are developed to meet the nature of science domain. Such labwork activities could be of the type challenging the hypotheses which Leach (2002) discussed, and thereby letting the students develop more sophisticated perceptions of physics and its nature. When doing meta-tasks it is likely the students will touch upon both the conceptual and the procedural skills domain in order to investigate and refine their hypotheses about experimental physics.

Vague problems are recognized as a way for students to develop their scientific attitudes domain; that is confidence in solving unknown problems. Vague problems are open in the formulation and the solution procedure, whereas the results are known beforehand (by their teacher). Such vague problems will most likely touch upon both the conceptual and the procedural skills domain, but these are not the primary goals of the task.

Finally are the *Christmas experiments*, which are developed only in order to develop the affective domain. This is included with a sparkle in the eye, but should though be taken serious. These days science at tertiary level experience massive recruitment problems and labwork activities hold the opportunities to evoke interests, and therefore should do so. But what is important to notice is that when engaging in Christmas experiments, which most likely would be with beautiful colours, blasts and explosions, unexpected phenomena or races and competitions, it is doubtful if learning in any of the other domains will occur.

The six purpose categories are now linked to different labwork types. The intentions with this framework is both seen as 'sorting things out', but equally so as a way to focus the design of a labwork activity to match it to the intended learning outcomes of the task in practise.

Which labwork activities are commonly used in physics in the Danish Gymnasium?

To answer the third sub-question: "*Which labwork activities are commonly used in physics in the Danish Gymnasium?*" a number of sources were investigated in order to give a list of typical labwork activities as well as the typical amount of labwork activities done in each of the three years. The typical series is developed by analysing internet-based databases where students upload their assignments as inspiration or help to other students. This gives a very clear picture of the labwork activities most often done. A number for the amount of labwork activities is found by collecting labwork series from a number of teachers. When presenting this list to others, great recognition is detected independently of the year group they are in. The list of typical labwork activities can be found in section 6.3.

Which type of labwork activities are the commonly used labwork activities (and thereby which types of potential learning outcomes do they hold)?

To understand: "*Which type of labwork activities are the commonly used labwork activities (and thereby which potential learning outcomes do they hold)?*" labguides from the official ministerial web-site related to the Danish physics teachers association were analyzed. To verify the above point of the commonly used labwork activities, all most often found labwork activities in the students' databases have a related labguide on the official web-site. When analysing these labguides it is found that all of them fall in the *exercise* category of labwork types, and according to the above framework therefore serve the primary purpose in the procedural skills domain.

Which specific purposes do the commonly used labwork activities hold?

This leads on to answering: "*Which specific purposes does the commonly used labwork activities hold?*", where each of the typical labwork activities' appurtenant labguides were analyzed in relation to the found sub-skills of the procedural domain, thereby providing a scheme for linking specific labwork activities to specific purposes, see table 6.11. Since this analysis is highly affected by the formulation of the labguide, the work is equally important as a training ground for doing similar analysis on own labguides.

9.1.2 RQ2: Does a declaration make a difference?

To answer the second research question: "*What is (if any) the impact on the students of a declaration of the teacher's intended learning outcomes of the specific labwork?*", again a number of sub-questions need to be posed.

The sub-questions are:

1. *What does 'declaration level of a teacher's intended learning outcome' mean, and how can it be measured?*
2. *What is the declaration level of the teachers' intended learning outcomes for the chosen cases?*
3. *What does 'impact on the students' mean, and how can it be measured?*
4. *What is the impact on the case students?*
5. *Does the impact correlate with the declaration level?*

Before going into detail with the sub-questions, first it was discussed and then decided to answer the second research question through observations and analysis of a (small) number of empirical case studies; that is observations and analysis of students' and teachers' engagement in labwork activities - as opposed to the answering of the first research question, which primarily was based on literature studies (and reflections thereof[1]), and as opposed to larger quantitative investigations, which in its nature demands to go less in depth and seeking for quantitative measures upon which to investigate and answer the research question.

It was chosen to do the empirical investigations based on four case teachers. For the case of the first two teachers (Alice and Burt), two student groups were followed, respectively. For these the teachers were granted full autonomy of the labwork topic, labwork design, labwork organization and labwork execution. It showed that these two 'naturalistic' case teachers held very different views on the purpose of doing labwork activities. This provided interesting data to be compared, but since the teacher, the school, the students and their socioeconomic backgrounds, the topic, the labwork, etc. differed, the findings could be correlated to either of these differences.

[1] What occasionally with a tickle in the eye is called armchair research.

Therefore two ‘experimental’ case teachers (Charles and Derek) were followed for two labwork activities each, demanding same students, same facilities, same topic, same apparatus (to as high extent as possible), but with very different declaration levels for the two labwork tasks. For the first labwork (halfwidth and halftime, respectively) the teachers were instructed not to discuss the learning goals of the labwork, whereas the other labwork (halftime and halfwidth, respectively) the teachers were instructed to discuss the learning goals as related to random and systematic uncertainties.

Teacher	*Students*	*Labwork*	*Duration*
Alice	Abraham, Abby	Equation of state	2×90 min.
Alice	Anita, Annie	Equation of state	2×90 min.
Burt	Brianna, Bridget, Brit	Conservation of E_{mec}	45 min.
Burt	Bobbi, Bonnie, Bob	Conservation of E_{mec}	45 min.
(Charles)	(Carrie, Camilla, Carl, Cam, Carolyn)	(Halftime)	(90 min.)
(Charles)	(Carrie, Camilla, Carl, Cam, Carolyn)	(Halfwidth)	(90 min.)
Derek	Dana, Daisy, David	Halftime	90 min.
Derek	Dana, Daisy, David	Halfwidth	90 min.

Due to a number of reasons one of the experimental cases was emitted (Charles’), and left were two naturalistic cases with each two student groups, and one experimental case following one group of students during two labwork activities, in total six labwork cases and two omitted from the part of the analysis concerning the students.

Having decided that the question should be answered by doing empirical investigations of a number of cases, it became important to decide what data to collect and what to look for in these data. For the case of each of the four sub-questions to be answered, it was chosen to do the analysis based on teacher interviews, observations of all lessons within the topic relevant for the labwork, collections of labguides, video recordings of the teachers’ introductions to the labwork, video recordings of the students’ laboratory work, student interviews, and collections of the students’ laboratory reports (possibly with the teacher’s corrections). Each of these types of data could shed light on any of the five sub-questions posed.

What does ‘declaration level of a teacher’s intended learning outcome’ mean, and how can it be measured?

As the second research question tries to correlate the case teacher’s declaration level to the impact of the labwork on the case students, first the declaration level of the teachers had to be clarified.

‘Declaration level of a teacher’s intended learning outcome’ means to which extent the teacher declare to the students what his or her learning goals of the specific activity are. The declaration level spans an interval, where at one outer the teacher is not discussion the learning goals at all (maybe because the teacher is not himself or herself aware of it), and at the other outer the teacher and the class discuss the learning goal to such an extent that all students are for sure aware of the learning goals and their relation to the specific labwork in play.

To clarify the declaration level for the case teachers, a triangulation between tree types of data was done in order to make the results stand stronger. The data types are teacher interviews prior to the labwork activity, analysis of the labguide and video footage of the teacher's introduction to the labwork activity. Each of these is investigated in order to detect how the teachers discuss the labwork activity and if they are making any references to their intended learning outcomes of the specific task.

What is the declaration level of the teachers' intended learning outcomes for the chosen cases?

Firstly, the teachers' were interviewed in order to understand their perception of laboratory work, both generally and for the specific labwork to be observed. Here it became obvious how the teachers held very different views on the learning potentials their specific laboratory work activities hold.

Alice discussed how she after having taught the specific labwork a number of times realized it was a good training ground for teaching the two procedural skills of variable control and graphical data treatment. The first, since four variables are in play in the ideal gas law, and each of them could take the role of the independent, the dependent and the controlled variables, as well as the need of controlling two of the variables in order to get an outcome domain which can be analyzed by the tools hold by the students. The second, since the students need to fit their data displayed graphically, and thereby can extract a fit parameter displaying a function of the controlled variables, which then can be compared to direct measurements thereof.

Burt hold the idea of labwork activities as a way to display theoretical concepts in reality and thereby bridging the world of theory to the world of phenomenon. He also discusses labwork activities as an alternative to blackboard lectures and calculations. These are not tight specially to the labwork in play concerning conservation of mechanical energy. For this he discusses scientific method(s), the idea of conservation and theory building, but it is not obvious if he discuss the entire module about mechanical energy, or this specific labwork.

Charles has one general plan with labwork activities, and that is to train the students for the upcoming experimental exam. As he perceive it the students especially need to display data treatment skills, and therefore the purpose of the labwork is to train these. For the two specific labwork activities of halftime and halfwidth he discusses probability as well as harmfulness of radioactivity.

Finally, Derek discusses labwork activities as having potentials both in relation to the conceptual domain, the procedural skills domain, the nature of science domain and the enquiry domain, though trying to downplay the conceptual domain, since he argues against the often found hypothesis that labwork activities verify the truth of what they have learned theoretically. Instead the conceptual domain should be used to emphasize how the theories are related to the natural world through simplifications.

From the interviews it becomes clear that Alice has given the learning potentials of the specific labwork in play a great deal of considerations, whereas the others are considering their labwork activities as a more general training ground for e.g. procedural skills, wherefore the nature of the labwork mostly plays the role of relating to the current topic, and maybe serving some conceptual arguments through that.

These outcomes were again proven by observations of the teachers' introductions to the class before the labwork. Alice spend a great deal of time on talking about her two intentions of variable control and graphical data treatment, and what she meant by it in relation to the labwork activity.

Burt, on the other hand, used his introduction time to go through the labwork apparatus as well as the data handling procedure.

Charles was intended to separate the two labwork activities such that he could discuss the learning goal of random and systematic uncertainties only in relation to one of the labwork activities, but due to a number of practical issues it did not go as intended, and therefore both labwork activities were given the same introduction. Also, looking at the introduction, it became clear the Charles had not taken the intended learning outcome of uncertainties as his own, and talked about them as my intentions. This was the main argument for emitting the data.

Derek was given the same assignment as Charles, and due to his research experiences and our discussions, he was better equipped for the task. The first labwork (halftime) was introduced without any discussion of the learning goals, and he only spends a few minutes on explaining the apparatus. For the second labwork (halfwidth), he dedicated almost half a module (approximately 45 minutes) on discussion random and systematic uncertainties and their relation both to the previously done labwork activities and to an example taken outside physics. For the day of the labwork, he did not comment on this learning goal, but only set the students to work.

Again the labguides were seen to correlate nicely with the results of the declaration levels, as these were first indicated during the interviews. Alice's labguide were packed with references to variable control and graphical data treatment, whereas Burt's had no such references. For the case of Charles and Derek the halftime labguides were cleaned for references, and for the halfwidth labguides references to the uncertainties were given.

Summing up these findings, the declaration levels of the teachers are seen to differ significantly, where Alice had a very high level of declaration, Burt had a very low. Charles was intended to have a high and a low level of declaration for his two labwork activities, but ended out stirring them both up, and Derek succeeded in having both a high and a low declaration level for his two labwork activities, respectively.

What does 'impact on the students' mean, and how can it be measured?

After having looked into the declaration level, it was time to investigate the impact this high or low declaration level had on the students. Where it was fairly simple to detect instances of references to learning goals (or the non-existence of such) in the teacher interviews, labguides and introductions, it was much more complicated to determine what to look for when investigating the impact.

For the cases where the teachers had clearly declared their intentions with the labwork, it was reasonable to look for placed in the collected data related to the students, where they are making some kind of reference to their teacher's intentions, but for the cases where the declaration level was low something else should be looked for.

In order to compare data from these different labwork activities, two ways of detecting impacts were used, one quantitative and one qualitative.

For the quantitative, a categorization tool developed especially for video footage of student labwork activities was found and adjusted to the data of this study. Here both the students' actions and sayings during their work with the experiment were coded for short time intervals. For the case of the sayings, the transcripts were coded after if the students expressed knowledge, doubts or reflections, and if so what nature this expressed knowledge had (technical knowledge, physics knowledge, combining technical and physical knowledge (KTP) and mathematical knowledge). If the students expressed a high level of the knowledge combining technical and physical understandings (KTP), it was perceived as an enhanced understanding of the labwork and its relation to the phenomenon in play - and thereby that valid learning took place during the labwork.

For the qualitative, the transcripts as well as the lab reports and student interviews were analyzed in order to find references to learning taking place. Beforehand the labwork activities with a low level of declaration were analyzed by use of the framework developed during the answering of the first research question in order to find its potential learning outcomes, thereby visualizing what to look for in the data.

What is the impact on the case students?

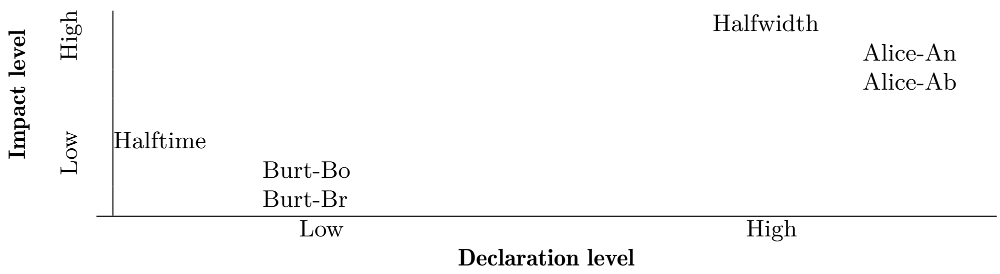
For the quantitative analysis, all six labwork cases were coded according to the scheme, and the findings showed the lowest level of KTP (knowledge combining issues from both the technical and physical side) for Burt's two groups. Thereafter followed Derek's halftime labwork. Alice's two groups had fairly high levels of KTP, and Derek's halfwidth labwork topped the data. Obviously the data differed very much in all of the coding categories, and a number of tests were done to see if the KTP levels were caused by different reasons, but all of these failed to change the overall picture of the KTP level. Obviously the results of such a scheme can be questioned, and this will be discussed further in the next section.

For the qualitative analysis, the data from the labwork transcripts, the student interviews and the lab reports were investigated in order to detect references to either the teachers' declared purposes or the found potential purposes. For the case of Alice's two groups, both accepted, used and addressed Alice's two intended learning outcomes, and during the student interviews both groups referred to Alice's introduction, where she stated her intentions with the labwork activity. In the reports it was obvious how they used their developed understanding of variable control and graphical data treatment in order to get through the reporting of their labwork.

For the case of Burt's two groups, during the labwork activity itself the students addressed a few of the potential learning outcomes, but at a fairly sporadic level, never digging deep into these issues. During the interview both groups were rather puzzled when asked what they expected their teacher to mean them to learn from the labwork activity. The reports were obviously written after the lab report scheme dictated in the labguide, though a few issues related to the potential purposes were shortly addressed.

For the case of Derek, during the halftime labwork the students addressed a number of the potential learning outcomes, especially since the results of the collected data differed quite a lot from the table value. In their reports they addressed these issues on a level similar to their reflections during the labwork itself. For the halfwidth experiment, the students did indeed address the issues of random and systematic uncertainties, and it was obvious from the data how the students tried the concepts out and developed a more refined understanding of them during the labwork. In the interview, though, they could not refer to Derek's intentions of the halfwidth labwork, but when presented to them they recognized the difference in the labwork introductions. In the reports the students obviously used a lot of time discussing random and systematic uncertainties, some with a greater understanding than others.

Figure 9.1 Diagram of the correlation between the level of impact on the students as a function of the declaration level by the teacher.



Does the impact correlate with the declaration level?

As seen from the case studies, both quantitatively and qualitatively the students' sayings during the labwork activities changes 'to the better' as a function of a higher declaration level, if 'to the better' equals more time spend on discussing the labwork's aims and relations to known physics as well as the quality of the reflections related to intended or potential learning outcomes, which the students have during the labwork.

Also the lab reports are on a qualitative higher level when the teacher has declared his or her intended learning outcomes of the specific labwork.

When the teacher has declared his or her intentions, the students take in these issues and understand their relation to the labwork activity itself in those cases, where the labwork learning purpose was at a high declaration level.

For the level of declaration as well as for the level of impact, it is impossible to quantify them. Still, it is possible to compare each of them and therefore place them in taxonomies. For the declaration level, Derek's halftime labwork has the lowest, then Burt's labwork, then Derek's halfwidth, and finally Alice's labwork. For the impact level, based on the KTP values, at the lowest level is Burt's Br-group and then Bo-group, followed by Derek's halftime and then Alice's Ab-group and then An-group, and topped by Derek's halfwidth labwork. The correlation between these taxonomies are tried displayed in a diagram (figure 9.1). It should be noted the 'axes' are not linear.

Displayed in this way, the impact level obviously correlate with the declaration level.

Whether these results are trustworthy, general and important are discussed in the following section.

9.2 Discussions of the findings

Turning towards discussing the findings, literature poses a number of ways to do so. E.g. Mason (2002) discusses *validity*, *reliability* and *generalisability* as the important factors to assess research findings, and Schoenfeld (2007) discusses *trustworthiness*, *importance* and *generality* as the three dimensions describing the ultimate contributions of a study. Wellington and Szczerbinski (2007) argue how Schoenfeld's *trustworthiness* overlaps with Mason's *validity* and *reliability*.

Schoenfeld (2007) describes his three dimensions as (Schoenfeld 2007, p. 21):

Trustworthiness Why should one believe what the author says?
Generality What situations or contexts does the research really apply to?
Importance Why should one care?

Taking of from the three dimensions, the findings of the two research questions will be discussed. Since the questions and the way they have been answered are so different in nature, the importance of either of the tree dimensions differs. And since the answering of each question is obviously intertwined, references between the findings and their discussions will naturally occur.

9.2.1 RQ1: Linking labwork activities and their potential learning outcomes

For the first research question about linking labwork activities to their potential learning outcomes, it was primarily answered by investigating literature and reflecting upon potentials in labwork activities.

Linking labwork types to labwork purposes

The discussion of the arguments for labwork activities was investigated through a number of channels, and based on this a sixfold categorization scheme was developed (conceptual, procedural skills, enquiry, nature of science, scientific attitudes and affective). Which categories and how many to be included is a choice - not an outcome, and is therefore not possible to prove (neither theoretically nor empirically). The easy argument for the six categories is that two are too few and ten are too many. A more complex argument is that the six chosen categories are different in nature, wherefore one cannot be reduced to a span of the others. Also, when looking through the literature, all normative arguments could be included in any of the six categories (the pure pragmatic arguments such as teaching variation or exam relevance are not discussed). The argument (or the lack of so) is identical to the argument of the chosen eight competencies in the KOM report[2] stating:

> We have reached the stage where we can gainfully identify eight central mathematical competencies. [...] The competencies are, as stated above, mutually connected, but they nevertheless each have their own identity. None of the

[2] The Danish project concerning competencies and mathematics

> competencies can be reduced to the remaining ones. Keeping in mind all the above-mentioned exceptions caveats, it can be useful to think of the eight competencies as making up a set of well-defined dimensions, which together encompass mathematical competence. Quite obviously it is impossible to produce scientific documentation that this is theoretically and empirically the case. Rather, there is a pragmatic assertion that these competencies as a whole encompass and encapsulate the essence of mathematical competence. Whether or not this claim can be upheld in practise is first and foremost dependent on its ability to withstand clarifying considerations and concrete use.
>
> (Niss and Jensen (2002), p. 44, translation from non-published official translation)

For the development of the six labwork types (experience, exercise, investigation, meta-task, vague problem, Christmas experiment), as well as their links to the different labwork purposes, almost the same argument goes. The categories have emerged in order to directly link the six purpose categories to six labwork types, and therefore the number of six labwork types was pre-given. The labwork types and their nature were based on collected descriptions of types of labwork activities along with own experiences. Therefore there obviously might exist additional labwork types, which does not fall into either of the categories, but most likely they can be seen as combinations thereof.

So, in Schoenfeld's words: "Why should one believe what the author says?" The main argument is that it makes sense to me; that I can hold the purpose/type matrix in my head; that all known labwork types and labwork purposes (besides completely pragmatic arguments) to my best knowledge can be included in the framework; and it has served for me as a way to overview and reduce a complex landscape into a readable map. Due to the nature of the question, the trustworthiness of the result cannot be judged by whether the reader *believes in* the outcome, but whether a reader potentially *finds use of* the framework.

It is then much easier to discuss generality and importance, or in Schoenfeld's words: "What situations or contexts does the research really apply to?" and "Why should one care?"

As for the first question: "What situations or contexts does the research really apply to?", the framework was developed on the basis of a broad range of research literature, grounded in many different disciplines (general science, physics, chemistry, biology, etc.), in many different school levels (lower secondary, upper secondary, tertiary) as well as in different school cultures. But it would be wrong to therefore conclude the framework is applicable to all these settings, since I have chosen the concepts, concerns, ideas and reflections, on which I have found the greatest use when analyzing the situation of physics labwork activities in the Danish Gymnasium. I have put great weight on the general education aspects; that is what the students learn during labwork activities should have a possible transfer to other situations, not only within the school labs, or the discipline of physics, but also of value in engaging in other school disciplines or situations outside the school. Especially for the tertiary level, this demand is only making half sense, since it is valid argument for labwork activities at tertiary level if they hold the potentials for gaining transferable learning usable in other lab situations or within the discipline (and even sometimes it is of value to be able to do the specific labwork without demanding potential transfer).

An argument for the applicability in other school situations is the (by now) significant amount of people (both researchers and practitioners) from different school cultures, school contexts, school disciplines and school levels, who have expressed how these findings could be relevant and useful in relation to their particular fields.

A somehow weird argument for a broader applicability is that the framework itself has proven to hold way too many possibilities, since more or less only the *exercise* labwork type is used in the Gymnasium (though here not regarding SRP, cross-disciplinary projects and special projects).

Probably going too far, this framework could be seen as a model of how one could address purposes of different general teaching methods, such as problem-solving, lecturing, field trips, etc.

As discussed in the introduction (chapter 1), there are a number of answers to Schoenfeld's: "Why should one care?", related to the importance of this framework. Since labwork activities are a significant part of the teaching of physics, this framework serves as an opportunity to touch upon some of the defining factors in physics education research; that is: why should we teach physics labwork activities?, what should we teach in physics labwork activities? and how should we teach physics labwork activities? To ask and answer such questions are of most relevance, both for researchers, curriculum makers, education politicians, etc.

Also for practitioners, this framework is perceived as most relevant, since it holds the potential to serve as some of the didactical thoughts, which according to the physics teacher quoted at the very beginning (page 9) are relevant, but that many teachers do not have the opportunity to have. Here of course there is an underlying premise that it is important to be aware of the reasons for doing labwork activities, and which labwork types serve these different reasons. This premise was the focus of the second research question.

Linking specific labwork activities to specific labwork purposes

As the first framework linking labwork purposes to labwork types was of a more general and normative kind, a second framework linking specific labwork activities to specific labwork purposes was developed. This had both normative and descriptive issues embedded.

To develop this other framework, the typical physics labwork activities used in the Danish Gymnasium were recognized and analyzed in order to place them in the first framework. The results were that all typical labwork activities were of the *exercise* type, and therefore held the primary purposes in the procedural skills domain. Recognizing the sub-skills in this domain, it was possible to match each typical labwork to its potential sub-purposes within the procedural skills domain, providing a second framework.

Again, the trustworthiness, generality and importance of this framework should be discussed.

One should ask "Why should one believe what the author says?" Developing the typical labwork series was based on counting up the uploaded lab reports on students' assignment databases, thereby recognizing a pattern of most often found labwork activities. There are of course a number of possible pitfalls in this method, which have been tried eliminated or argued against (see chapter 6). These typical labwork activities were then translated to labguides by using the labguide database for free download and use on the web-page administrated by the Danish Gymnasium physics teachers association under the Danish Ministry of Education. As this is the most official channel for finding labguides, it seemed the most valid choice, but its should be added that most teachers alter the labguides in order to adjust them to the taught topic, school equipment and time allotted. Therefore a teacher can also change the type of the labwork, and therefore fall into a completely different list of sub-purposes from another purpose domain. Also, a reader could be disagreeing upon some of the recognized potentials (or even the understanding of some of the sub-skills) in the labwork, and might therefore want to place the crosses slightly different.

As seen, there are a number of reasons to question if the labwork activities, the sub-skills and their links are the most believable choices. Besides arguing for the chosen labwork activities, sub-skills and links in a hopefully believable way, it should be noted that the filled out matrix itself is not as importance as proving the possibility of doing so. Since each teacher operates with his or her own labguides and lab designs, it is more important that the teacher is shown how to reflect upon their labwork activities in relation to the relevant purposes and sub-purposes, as to whether one cross should be in one place or another in the matrix, or one labwork should be replaced by another, or one sub-skill should be added or removed. It is of course an easy way out when discussing the trustworthiness of the research to state that it is not the findings which are important, but showing it is possible to gain findings.

The same argument is found when discussing the generality of these findings. By its nature the framework is not intended to be general. But showing the possibility of doing so is transferable to a number of situations and contexts (equalling the above mentioned different school levels, school cultures, school systems and school disciplines.)

The recognition of the sub-skills filling one of the axis are though general in its nature, and it should be possible to replace the labwork axis with other typical labwork activities (or just the labwork which the reader is interested in), and using the framework as a basis for analysing this particular labwork or labwork activities.

At first notice the second framework might not be 'as important' as the first, which was of a more general nature and thereby showed to be important to a much larger audience. I though claim that this framework shows how the first framework is not just an 'up in the air'-discussion, but actually can be used to dig into real examples. Without this second work, no prove of its use in practise was given. Also, without examples this field of physics education research often tends to be filled with rubber words, wherefore we are all agreeing or disagreeing, without really understanding what each other are talking about. So the second framework is important in itself, but is also important as an exemplification of the first framework. And therefore, if one cares for the first framework, one should also care for the second.

9.2.2 RQ2: Does a declaration make a difference?

Three parts of the answering of the second research questions should be discussed, namely the declaration level, the impact on the students, and the correlation between these.

First the trustworthiness of these three parts is discussed, that is: "Why should one believe what the author says?"

For the case of the declaration level of the teacher, three types of data gave access to information (teacher interviews, labguides and labwork introductions), and it was found how the results of the three data types showed a significant degree of correlation. For the case of the interviews, it is apparent that teachers can say one thing and do another, and such were detected, but the correlation between the introductions' and labguides' level of declaration was severe.

The most important issues in relation to the declaration level, is the understanding of 'potential learning outcomes' used throughout this study, and those should be objected against under the previous research question. It is obvious how some of the case teachers disagree of my interpretation of valid arguments and purposes for labwork activities, and therefore does not understand my questions about their intentions with their specific labwork activities. But investigating the declaration level within the frame given by the answer to the previous research question, the data triangulation between teacher interviews, labguides and labwork introductions provide a strong answer to questions about the declaration level, since perfect correlation existed between the labguides and the teacher's introduction to the labwork (and for some of the cases also to the interview).

Another relevant issue, since the nature of the second research question summons comparisons, is to place the declaration levels of the different cases along an axis (or at least labelling them as either having a high or a low declaration level). As in the end the two naturalistic cases by chance served as a fine measure for high and low declaration levels, respectively, the two experimental cases should then each provide the study with similar high and low declaration levels. As was the case of Charles, it proved to be more complicated than expected, and for the case of Derek more work was put into explaining the research design and the arguments behind it. The two labwork activities of Derek's then ought to be similar in declaration level as Alice's and Burt's respectively, and though it is not possible to quantitatively give a measure of this, the levels displayed in the labguides and the introduction to the labwork clearly indicated a significant difference, and a obvious mark of which having the high and which having the low declaration level.

More complex is the answer when turning towards the impact on the students, since the concept of 'impact' by choice is fluffier than the concept of 'declaration level'. Here again data triangulation was done in order to investigate the impact in a number of ways, but in the nature of the question it is much more complicated to points towards these sought for impacts. The data investigated were video recordings of the students' engagements (action and sayings) during the labwork activity itself, as well as student interviews and collections of the lab reports.

Again, similarities and differences were looked for. To be as fair as possible to the data set, it was analyzed in all found relevant ways. First the data from the video recordings were analyzed quantitatively. As described, many doubts as to whether this method would provide any reliable as well as interesting answers were had. In section 8.2.4 the details of the validity and reliability of the coding tool were discussed, and though a great work was put into testing, diminishing or arguing against possible 'inreliabilities' of the tool, still it was concluded that such results should never stand alone. Believing in the results of the quantitative analysis, it showed significant differences for the six labwork cases in favour of a correlation between declaration levels and impacts on the students, also when taking uncertainties into account[3]

The rest of the data analysis was qualitatively. In order to detect impacts on the students of high levels of declaration, it was obvious to look for places in the data where the students addressed or touched upon the declared intended learning outcomes. All student groups addressed their teacher's intentions a number of times, and it was obvious how their understanding of them increased during the labwork activity (and apparently further on in the writing of the lab report, where the students' understanding of the learning goals had gone to an even higher level). In the interviews with the students they were not all able to recall the teacher's declared intentions, but when presented with them, all groups remembered. The fact that not all students recalled their teacher's intentions indicates that a part of their addressing of the teacher's intentions was due to the design of the labwork, and not only due to the labguide or labwork introduction. For those cases with a low level of declaration, the labguides were analyzed in order to find potential learning outcomes embedded in the design of the labwork activity. Places where the students addressed or touched upon any of these potential learning goals were detected. Comparing the level upon which they discussed these issues with the cases of a high declaration level showed differences, again with a higher quality for those cases, with a high level of declaration.

Two issues ought to be discussed in relation to the quantitative and qualitative results. Firstly, is the detected quality difference of the impact on the students believable? And secondly, could the quality differences come from another quantity not taken into account? For the first question, I can only say that I have laid out the data as objectively as I could, and when doing so I see an obvious difference in the quality level. But I acknowledge that others could read the data differently and therefore argue against the interpretation. This is always the issue when doing case studies. For the second question, the study design was done so as to try to diminish such quantities, by both doing naturalistic and experimental case studies. But it was obvious, especially in the analysis of the lab reports that the students were already at this stage relying on solution strategies for doing the lab reports (and therefore possibly also for doing the labwork activity itself), which of course has an immense affect on the quality of discussions and reporting. And these solution strategies might differ due to such quantities as the grade point average of the class, their prior education in elementary school, etc. etc. Therefore there is something potentially problematic in comparing different cases. This should though not be the problem of the experimental cases, but here instead there is the issues related to the students having learned from the first labwork when doing the next, which could be the real cause of the higher impact level. But as previously argued it could also

[3] Though the error estimate giving the size of the error bars was for sure very poor.

have the opposite effect, since the students could have debated out the relevant issues in the previous labwork, therefore not feeling a need to discuss or report it for the second labwork.

For the case of the generality, that is: “What situations or contexts does the research really apply to?”, it needs to be discussed what role the cases have. It is not claimed that these cases are representative for the physics teachers and students in the Danish Gymnasium. If this study was trying to describe the present state of a typical class, it was naturally of great importance to argue for the chosen cases to be representative. For this study though, the teachers are not representative, since one of them has been engaged in school book writings, one has been engaged in developing studies for the Ministry of Education, one has chosen a teaching career as an easy way to get a steady job, and one has a PhD degree in physics education research. These are fairly extreme cases, and it has a point to it. To look for differences, if is much easier to detect them in cases mutually very unlike, than for cases almost similar.

The findings showing indications of a strong correlation between declaration level and impact level are applicable for cases in other situations and contexts, since looking into a possible correlation is a very general pedagogical question. So why should one use the special case of physics labwork activities in the Danish Gymnasium to look into this general pedagogical question. As discussed a number of times, labwork activities put the problem on the edge, since labwork activities are time consuming, expensive and have the potential to have so many things going on at once that it is impossible to keep focus on the real point of the activity. Therefore it is especially important to declare the focus of the activity in the school laboratories in order to help the students reach the intended learning outcomes.

Thereby the issues of importance have also been answered. “Why should one care?” Because it is an answer to a question, which should be posed in all teaching situations. What is really the purpose of this activity?; what is the intended learning outcome? Then one could discuss at what stage in the school system students are ready to take in this information and use it. As discussed previously, obviously babies do not benefit from being told how crawling is important in order to train their balance and falling skills. For this study strong indications of Gymnasium students being ready to take in this information and use it are given, concurring with studies of metacognition at upper secondary level.

Finally, it should be discussed why the students were not tested at a later stage (e.g. a year later) on their abilities to put the teachers’ intended learning outcomes in play in other labwork situations. This could for example have been done by analysing later lab reports related to labwork activities having the potentials to address the same learning goals. The real reason for this not being done is that it was not thought of in proper time. But it would also have been difficult due to more practical reasons. All observations were done around Christmas, and the school year ends late April, so not even half a year could have been reached. Also, the teachers try to jam the labwork activities in the first part of the school year, to be sure all students (even those needing several deadlines) have made the lab reports before an exam. Therefore there would not have been that many later lab report examples to take from.

9.3 Implications of the findings

In the previous two sections, the research questions and answers were summarized and discussed within their own frame. In this section a step back is taken, and the arguments for asking and answering the questions are looked into, thereby also revealing implications of the findings.

Interestingly enough, though six potential learning outcomes of labwork activities - and with that six labwork types - were recognized, only *one* of these labwork types was found implemented in the physics classes at the Gymnasiums. Though maybe not very surprising, it shows how poorly we are presently using the potentials which laboratory work activities hold, and that there are many possibilities waiting to be used.

Taking off from the findings of this study, it could be of great interest to investigate if and how the developed framework can provide an aid for other types of labwork. Investigating special projects in the Gymnasium physics, looking into chemistry labwork activities, looking at tertiary level, or going towards other school settings such as HTX, could provide further insight into the possibilities and potentials these labwork activities hold.

So, why is it that in the physics laboratories in the Danish Gymnasium only the labwork type of *exercises* is used, and thereby only putting procedural skills as the primary purpose of this teaching method? As already discussed, it is most likely a blend of curriculum demands, culture, tradition, bureaucracy, as well as this labwork type provides the teacher with the best results, measured on the inner effectiveness (the students *do* what the teacher intended them to *do*, see section 4.6.2).

But what Alice has shown us is that it also holds the potentials for being effective on the outer effectiveness (the students *learn* what the teacher intended them to *learn*, see again section 4.6.2) - though not necessarily taken into account. Alice showed us that specific labwork activities can be analyzed in order to reveal its potentials, and thereby why this specific labwork is an exemplary example of something which's relevance goes far beyond the labwork itself. And with this being clarified, both Alice and Derek showed us how it is possible to teach after the potentials of the specific labwork, such that the students recognize, accept and gain an enhanced understanding of the intended learning outcomes, when this being declared.

So what it shows is that within the frames given to the teachers (time, equipment, curriculum, etc.) it is possible to change labwork activities from being only a curriculum-demanded teaching variety with fluffy general (and unmet) purposes into a goal-oriented activity, where it is obvious how the labwork is chosen especially for its ability to serve as an exemplary example of the goals. And that these goals are of great value, also for other labwork activities, for the learning of physics, and even outside the physics classrooms.

As Timmermann Ottesen in her PhD thesis of 2009 investigates mathematical proof as a way of teaching mathematics, I can look at laboratory work as a way of teaching physics. And in that sense, some of the same things can be said. Proofs in mathematics hold a defining role of the epistemology of mathematics in the same way as experiments hold a defining role of the epistemology of physics. But this does not mean that either proof making or laboratory work is the best way of teaching mathematics and physics, respectively.

So could it be that laboratory work should be given up as a teaching activity? Possibly - but the reality is that physics labwork activities have been used as a teaching activity at secondary level for more than a century, and there is no indications of them leaving the school scene.

So could it be that the type and form of the laboratory work should be dramatically changed? Research and developing studies have throughout history tried to change the type of labwork activities used, in periods placing emphasis on inductive labwork activities, enquiry labwork activities, P-O-E's, problem-based labwork activities, etc. etc. Still studies have shown how the use of guided labwork activities is quite stable. As for a Danish setting, the stability is also recognized for the specific labwork activities used, both across the country and across time.

So while still cheering for dramatic changes in the labwork practise, I emphasize that teachers should articulate reasonable learning arguments for their specific labwork activities (and possibly finding ways to do so by the findings of this study). This study has proven it possible as well as worthwhile.

9.4 Personal closure

At the very first pages of this thesis I have expressed my wonders of why labwork did not appeal to me before the end of my physics studies (see page 14).

I am now able to answer that question. I did not perceive laboratory work during my master thesis as a learning activity, but as engagement in a piece of research. Before that, laboratory work was sole an activity designed to teach me something which I did not understand what was. Therefore it was obviously to me making hard work out of nothing (at least not anything beneficial).

Now I understand what the labwork activities *could have* taught me - and maybe actually *did* teach me. I am now taken on a new quest in becoming a physics Gymnasium teacher, and I can hardly wait to see how these insights will affect my own teaching, and even more importantly my future students' learning.

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Part VI

Appendices

A The Danish school system

This small appendix serves as a short overview of the Danish school system to understand the role and function of the Danish Gymnasium.

The official education in Denmark starts at the elementary school at level 0, where kids are of the age 5-6. This compulsory school continues on to level 9 (age of 15-16), and can be followed by an additional year of level 10. Typically this compulsory education takes place at the same school throughout all 10 years. The students belong to a certain class of students and often have the same set of teachers during their entire compulsory education.

After the compulsory education students can continue with a vocational education (which the vast majority does). Students are to choose between two branches:

- General education qualifying for access to higher education
- Vocational or technical education qualifying primarily for access to the labour market

The general education is split in four: the general upper secondary education provision of the Gymnasium (STX), the higher preparatory examination or HF-programme, the higher commercial examination or HHX-programme and the higher technical examination or HTX-programme. The general education takes in more than 60% of the cohort.

This project concerns the general upper secondary education provision of the Gymnasium (STX), referred as the Gymnasium. The Gymnasium programme consist of a broad range of subjects in the fields of the humanities, social science, and natural science, including compulsory physics throughout the second half of the first year, and vocational physics on either a one or two year additional level. Approximately 40% of the students leaving the compulsory education chooses to continue at the Gymnasium.

Leaving the general educational system with a passed exam, approximately 75% of the students continues with further education within the following 27 month (data from the web page of the Ministry of Education).

In section 5.1.1 the history of laboratory work in the Danish Gymnasium is reviewed and in chapter 5.1 the current curricula of the Danish Gymnasium is reviewed in relation to the laboratory work activities in physics. In section 6.3.1 the core topics of the physics curricula of the Gymnasium are investigated.

B Interview guides

In the following the used interview guides can be found. For the observations, the teacher has initially been interviewed. After the observations of the labwork the students have been interviewed. In the case where the labwork has taken place over two days, the interview guide for the students are split in two (as seen in the following), for the case of only one day, the students have been interviewed according to both interview guides.

B.1 Interview guide - Teacher

This is the interview guide given to the teacher prior to the lesson sequence including the labwork activities, which I am to observe.

B.1.1 General

1. What is your own background in physics (major, bachelor, experimental, theoretician. . .)
2. How many years have you taught physics in the Gymnasium.? Why have you chosen the job of teaching physics in the Gymnasium?
3. What is the most important one should learn in physics in the Gymnasium (level C, level B, level A)? Does labwork contribute to that?
4. Can you teach physics in the Gymnasium without labwork or demonstrations?
5. How do you perceive labwork activities: labwork activities are used to illustrate theory, theory are used to explain experimentes. . .
6. When preparing a teaching sequence, do you typically think of experiments and then theory, or is it the other way around?
7. How restricted do you feel by the curriculum?
8. How restricted do you feel by the equipment collection at your school?
9. How do you perceive and what is your experience with bounded versus free experimental teaching modules? (Bounded/free to choose the experimental topic, the experimental setup, the reporting. . . ?)
10. How do you learn? What is your experiences of when and how learning occurs, both for you personally and for your students.

B.1.2 The class

1. How is the class and gender distribution of the class?
2. How do the class operate: vocational, social. . . ?
3. How interested are they in physics?
4. Do you teach them in other disciplines than physics, and if yes, how are they in that class? If no, what does the other teachers say about the class?
5. How are the class functioning during labwork activities? (concentrated, playful, conscientious. . .)
6. How do the class perceive labwork activities? (fun/boring, difficult/easy, worthwile/waise of time. . .)

B.1.3 About the sequence

1. What have you planned for the sequence?
2. How have you planned the sequence?
3. What should the students learn from this sequence?
4. Have you had any considerations about what the students learn besides states of matter / mechanical energy / radioactivity in this sequence? (Sense of dependent and independent variables, connection between graphs and equations, connections between data and theory, laws of nature versus laws of mathematics. . .)
5. To which degree do you expect to realize what the students have learned from this sequence?
6. Do you make the students aware of what you expect them to learn from the sequence (didactical contract)? If yes, explicitly or implicitly?

B.2 Interview guide - Students - first interview

This is the interview guide for the first interview I do with the students. I interview them in groups, and the groups are identical to the labwork working groups.

B.2.1 General

Introduction

1. Why have you chosen the line with physics, chemistry and math on the level you have?
2. Are you happy with your choice?
3. Do you think physics is a difficult or easy discipline?
4. What are you planning after the Gymnasium?
5. Do you think all students in the Gymnasium should have physics on level C? (why / why not?)

6. What do you think one should learn in physics in the Gymnasium?
7. Is labwork included in that?
8. What do you think about doing labwork activities?
9. How do you perceive writing the reports?

B.2.2 The experiment

Expectations

1. Did you attend the class where the labwork was introduced?
2. Did you read the labguide beforehand?
3. What do you thing your teacher wanted you to learn from this labwork?

The experiment

1. Describe the experiment and the procedure.
2. Do you think it was fun doing the labwork?
3. Do you think the labwork was instructive?
4. Have you realized something from doing the labwork which you would not have gained from working with the topic in e.g. problem solving classes?
5. Do you think a demonstration would have been equally good?
6. Do you wish there were more freedom in the labwork to choose what to measure?

B.3 Interview guide - Students - second interview

This is the interview guide for the second interview I do with the students.

B.3.1 The labwork

1. Describe the labwork to me.
2. How careful have you read the labguide?
3. How do you perceive this labwork? (fun, educational, boring. . .)
4. How would the differed, if it was a demonstration?
5. What do you think your teacher wanted you to learn from this labwork? (If not said, address the teacher's intentions as given in the teacher interview)

B.3.2 General goals

1. What do you think you should learn in physics in the Gymnasium besides equations?
2. How is physics in the Gymnasium different from chemistry / mathematics / biology?
3. What do you gain from the different disciplines?
4. What does the different disciplines train?

5. How are labwork activities in chemistry / biology different from the ones in physics?
6. I imagine physics in the gymnasium can be justified by e.g. one of these statements: ‘physics prepare me for further studies’ or ‘physics prepare me for engaging in the real world’. Where on the scale spanned by these statements do you feel physics are placed? Or do you perceive different reasons for having physics?

C Additional data from the teacher interviews

In this appendix additional findings from the teacher interviews are given. Three questions are answered through the interviews, each found in the below three sections. The questions are:

- What should Gymnasium students learn at their physics classes?
- How has the design of this particular labwork activity evolved?
- Will the students be aware of the intended learning outcome of the specific labwork activity?

C.1 Why learn physics?

In the introductory interviews the teachers were asked for their reflections upon why the students should learn physics in the Gymnasium.

C.1.1 Alice - why learn physics?

When asked about the most important thing to learn in the physics class, Alice initiates by talking about teaching them something to remember:

118 **Alice** That they learn something they remember afterwards. It is very impor-
119 tant, the thing about everything not being forgotten the next day. Even
120 though the skills disappear extremely fast, rather scary isn't it? But when
121 they read something in the newspaper or something, and they recognize
122 it and say 'yes, that is correct, I learned something about it once'.

As she states, she is aware that many things will be forgotten. But keeping little pieces of knowledge and understanding in the back of the minds of the students are what she perceives as the most important.

She continues talking about affective reasons:

122 **Alice** And the joy one can have in understanding some connection. I would also
123 like them to experience that.

This is not only about having fun while being in the physics class, but it is about learning to like physics.

She finish up the discussion about the general reasons for doing physics in the Gymnasium by listing two goals: to know some physics, and to like it:

Alice One of the goals is for them to know something about physics; when they look out the window and sees it is raining they think about how water condense up there in the clouds. And they think it is exiting. My goal of my own teaching is partly to make the students think it is interesting, that is a big victory for me. And if I can also make them good at it, to do well at the exam, because I know how important it is for them. So it is like the two things which are my ambitions. And that the weak students do not completely fail, that I also think is... But that is not so much about what to learn, is it?

In the end she mentions the exam, but primarily because it is important to the students and is a picture of gaining knowledge of physics. This should be contrasted with Charles, who places a lot of emphasis on the exam.

C.1.2 Burt - why learn physics?

In the introductory interview with Burt he also touched upon the reasons for placing physics in the row of disciplines of the Gymnasium curriculum.

Burt talks about the twofold goal of all disciplines in the Gymnasium, namely general education and vocational reasons:

Burt Because for some, it is on a rather modest level. So relating it to general education[1] and to be able to manage oneself in society and respond to it in a fair way to what one meets of physics related problems. And for those, it is these things which are in focus. And then there are others who will end out working with it; it will be their profession or something close hereby. At a later stage. And they have to gain a totally different kind of physics. To be able to do more things on their own. Calculate things, and possibly do practical things on their own. So there is not one thing that is the most important, no.

So as he explains, for the first compulsory level, the general education of physics is in focus, whereas on the later levels, the general education arguments are supplemented with vocational reasons, since it will be likely that the students will pursue a career in physics or science of some kind. These vocational reasons can be understood as the ability to calculate and experimentally test various things. He perceive these two arguments as very different.

From here on he explains further what he means with general education related to physics, relating it to climate changes, orders of magnitude, etc. When explaining the vocational reasons, he states:

Burt At least to be able to use models. And the thing about understanding what a model is and in some simple cases to be able to do it, is probably something which is central. Well, to take something complicated from the

[1] In Danish: almendannelse

79 real world and to extract the important things and to do something which
80 is simple and clear. I think it is something everybody can have use of.
81 And here physics is definitely of some help.[. . .]
90 **Burt** To have a sense of, again, what physics is and how you work with physics,
91 and how the results of physics occur. So it is also about the scientific
92 method, empirical data, and forming of theories and these kind of things.
93 But they do not have to do to much of it themselves.

His previous statement about calculating and experimentally working with these things is now elaborated by including modelling, epistemological understanding of physics, and scientific method. His does, though, not expect the students to be able to build up models (experimentally or theoretically), but to be able to work with models presented to them.

C.1.3 Charles - why learn physics?

In the interview with Charles, he talked about the general goals of Gymnasium as a balance of between general education, core content and competencies. I asked him which of these three goals he place emphasis on, and to what extent:

440 **Charles** Then I place emphasis on general education and competencies. Because
441 the core content, it is there, I know it. But as I have tried it out the last
442 couple of years at the exams, I had quite different external examiners.
443 Actually, an old nice one and an old grumpy one. And then we agreed
444 - mostly - well - for the most students we agreed upon the grade, there
445 was almost no doubt. And there we focused almost not at all, as I also
446 tried to explain them [refers to a talk about the exam in class] during the
447 labwork on whether they could plug the cords correctly, etc. Because, I
448 know, you used to focus on that, it was really the focus point earlier on.
449 There you focused on every second of the exam, but now you think - like -
450 more generally. Well, the student is not to be an electrician who has to be
451 able to plug in the cords correctly, but what is really like most important
452 for the student is to e.g. learn to do data treatment, well to use an excel
453 spread sheet or the like, because if you are to become a nurse, a doctor,
454 or an engineer or the like, well you need to be able to use a computer.
455 And the working with data, as we do in science teaches you to do data
456 treatment, and it is like, the core of it. Like earlier on, oh my, well, you
457 god damn had to set it up correctly, or you would fail. Even thought
458 everything you said was correct, if you could not set it up correctly, then
459 you failed, and I am sure it was like that earlier on. It is not like that
460 today at all. Of course there is certain things they are to know, and that
461 is why you have the core content in the curriculum, but it is freer now,
462 well, 60 percent is what you call core content, but the rest is free. And
463 that is fine, that is great.

Charles turns the talk about what to learn in the physics classroom to what the student should be able to do during the exam. This is the way Charles thinks about teaching in the Gymnasium. His reasons for the students to learn physics are for them to pass the exam. He shows off this point of view many times both during the interview and during his classroom teaching.

But what he says beside this is how he place emphasis on the general vocational arguments of teaching physics, like being able to operate computers and typical software. This he put up against being able to operate apparatus, in a more narrow technical sense.

C.1.4 Derek - why learn physics?

Derek explains the purpose of learning physics in the Gymnasium as a new way to perceive the world:

258 **Derek** I actually think the best you can give to the students is somehow to
259 change their way of perceiving the world.[. . .]
263 **Derek** And therefore I think that in physics it is the academic virtues which is
264 worth chasing after. As opposed to some idea of the usefulness of learning
265 physics in a practical sense. [. . .]
269 When I fare in my everyday life it is very rarely I meet a specific problem-
270 atic situation where I say that it is good that I am a physicist, because
271 now I now what is about to happen. [. . .]
278 **Derek** I believe physics is a way to think - to relate to reality to with a new
279 tool. A new approach to reality, which is quite important. And it is very
280 important for two reasons, physics is.

Derek continues by setting up two arguments for the importance of gaining the 'physics' way of perceiving the world, namely the power of prediction and the power of abstraction. For the first he states:

281 **Derek** Because physics can, physics is one of the only disciplines which actu-
282 ally can come up with powerful predictions and thereby points towards
283 what is up and down in this reality. You can't play on Odset [A Danish
284 betting system] on the next transit of Venus. You can play on all sorts of
285 society-related or humanistic or cultural and all sorts of things. But you
286 can't in physics. It is pretty wild that we actually somehow can have a
287 natural science which very precisely can predict things like the position
288 of the celestial bodies in relation to each other. And there is something
289 philosophical-psychological in that.

For the latter argument of abstraction, Derek says:

290 **Derek** And then there is the big thing in it, which I also cherish, and that is
291 when we teach our students - or try to teach our students - that there is a
292 lot of the natural phenomena, which can be described under the same hat

with some theory, so you can explain a lot of the natural phenomena. That provides you with the ability to think abstract, first because you think in line of theories. But also the ability to feel less alienated towards the world you walk around in. Not feeling alienated I find very important.[. . .]

Derek And not just to explain science with fancy concepts and theories, but that they actually gain an idea of how these fancy concepts and theories are related to a specific way of investigating nature.

He ends out by concluding:

Derek That they are not frightened or alienated by natural phenomena and their scientific explanations. And they know there is a certain way to address nature and have tried to address nature in that way. And that something is true and false. And I could go on with the impact on our history of ideas and our perception of the democracy and so on.

Derek talks about school physics as an entrance into being able to understand and address the natural world, which will prevent the alienation, which often grows when students start to see the complexity of the world they live in. Physics can give the students the feeling that something is predictable and understandable in an otherwise un-predictable and un-understandable world.

C.1.5 Comparison - why learn physics?

For the first year Alice, Burt and Charles place most emphasis on attitudes, interests and general education. On the more advances levels the vocational reasons come into play, along with general education arguments.

Alice underlines the importance of learning some physics and liking to do physics. So she place emphasis of conceptual and affective reasons.

Burt on the other hand place emphasis on general education and vocational reasons, where the first is related to being able to follow debates in society such as the current climate debate, and the latter is relating to modelling and epistemological understanding of physics. To be able to perform models, etc. is thought not something, which he expects students to be able to do after finishing the Gymnasium, but to be able to work with existing models and views of physics are expected.

Charles places most emphasis on teaching the students to do well on the exam. He explains the focus of the exam has shifted over the last couple of years from a very technical focus (e.g. setting up the apparatus) to concern more the data handling in ways that also have a value outside the physics classroom.

Derek talks about physics in the Gymnasium as a way to change how the students perceive the world they live in towards understanding the 'scientific virtues' used to understand the natural world. By this he means to understand the grandness of being able to predict physical occurrences and being able to see how different phenomena can be explained by the same theories. This causes the students to be less alienated of the natural world, and this dis-alienation could possible interplay with their understanding of democracy and history of ideas.

C.2 How does a labwork develop and evolve?

The teachers were asked how the design of the labwork activity evolved.

C.2.1 Alice - how does a labwork develop and evolve?

Alice explains how this particular labwork has evolved over time, as she has run it several times:

Alice One starts with experiences from colleagues. See what they have done, and then the ideas come on their own. And suddenly one gets ideas for some experiments. This experiment, it actually started with something I read in LMFK[2], a journal is published. It described the exercise in another way, but it was the equation of state to be verified, and it was about using a weight from the kitchen and a syringe of plastic and so on, and that I have run several times. Then we had new techniques for measuring with digital data collection and stuff. . . it did not work very well, because it was. . . And then it changes and such things.

Here she tells how the ideas for the labwork activity emerged from an idea in the Danish journal for physics teachers. It was initially based on something which sounded like it could work. The changes made were related to making the labwork run better.

Later she came up with the intended learning outcomes of variable control for the labwork activity:

Alice And it was actually only last year I came up with this variable control thing, and I have actually always assumed, yes, but of course it is obvious that you can not vary several things at the same time. But last year I thought, no now I will try to do something extra, and then they did not do exercises, not in this way. But then I realized that it was not, you know, it was not easy for them. And then I took the first exercise, it was something with waves on a string. First I talked with them about gas . . . as an example; it has such a lot of nice variables. And then I led them do these waves on a string, where they had to make out themselves which measuring series they were to do. And then I realized that when I came through with these experiments more or less like I used to in the second year then a really lot of them that could use it. And let them do it themselves, yes what is it to keep constant and what is to be varied.

[2] Danish journal for mathematics, physics and chemistry teachers in Gymnasium.

She explains how the labwork needed some adjustment to get it right.

Finally she tells how the theme of the variable control changed the labwork:

230 **Alice** And it gave a much better understanding of the labwork, I think it actually
231 worked, and I decided to use it again. And then I thought this time I will
232 choose this instead, because I have done things in a totally different order
233 this year then I use to, because I have this class in three years, so I do not
234 have to allocate the first year for this and the second year for this. Now I
235 am exited about how it will work.

Here she talks about better understanding as the success criteria, whereas the early changes were centred on practical issues.

C.2.2 Burt - how does a labwork develop and evolve?

Burt does not remember in the same way how this labwork has evolved, and he only states:

154 **Burt** By now, when I have been in the business so many years, I do not think
155 that often about it. Because I have gotten used to some things, which I
156 think works, and then I just do that to a certain extent.

He talks about his criteria for success according to what works - underlining removing obstacles along the way and not necessarily testing it against the students understandings.

C.2.3 Charles - how does a labwork develop and evolve?

Charles has only tried out this labwork a couple of times before. He seems to not really remembering (or not wanting to tell me) where the ideas for the labwork came from, but he denials my guesses of colleagues or textbooks. Instead he finally says:

341 **Charles** To be honest, I just went into the storage and found the material, which
342 was available, and then I said okay, and I just used it.

He found equipment for the two labwork activities in the storage and used them for the radioactivity topic, because it was what was easy available.

He was also asked for his ways of evaluating and thereby evolving the labwork activities:

291 **Charles** If there is an error or a typo, or if it just too hard, or it needs more
292 hints etc. It is done every year. It is not like it keeps me up at night. It
293 does not really take any time.

It seems he did not really understood the question the intended way, since for him he underlines the importance of correcting errors. Still he argues for including additional hints in case of the students not being able to finish the task without problems. Like Burt he talks about evaluation of the labwork task in relation to removing obstacles along the way.

C.2.4 Derek - how does a labwork develop and evolve?

Due to my involvement in planning the labwork task, we do not discuss how the labwork activities were planned and has evolved. At another situation he let me know he was in the writing of the labguide inspired by various internet sources.

Derek But I try to plan physics B based on the labwork activities we can do. Then is something like looking into the cabinets to see what we can play with. And what sorts of things I can make with them about it?

C.2.5 Comparison - how does a labwork develop and evolve?

Alice is very aware of the development of this labwork activity, knowing where it took of from and how it evolved. She states her over-aching intended learning outcome of the labwork task, control of variables, only came after a number of years running the labwork activity. She talks about her evaluation criteria as her realizing and declaring her intentions with the labwork increased the students' understanding.

Burt on the other hand cannot remember the development of the labwork task, and it is evaluated and redesigned based on removing of possible obstacles, which the students encounter.

Charles has chosen the labwork task primarily because of apparatus being present in the storage room. He also talks about evaluation and redesign based on removing obstacles the student experience during the labwork.

I have actively engaged in the planning of this labwork, wherefore the discussion of the development is a joint-venture between us.

It becomes quite obvious how the teachers evaluate and reflect upon their labwork activities in quite different ways. This has been an entrance into investigating the teachers' rationale for choosing guided labwork activities, which work on another level of evaluation criteria than expected from a physics education researcher's point of view (see section 4.6.2).

C.3 Will the students know the purposes?

I asked the teachers during the introductory interviews if they expect the students to be aware and knowledgeable about the teachers' intended learning outcomes of the labwork task.

C.3.1 Alice - will the students know the purposes?

Alice tells she is not sure if her students will be able to explain her intended learning outcomes of the labwork task:

Alice Maybe if you ask them, what have you learned by this labwork, then I
will not be surprised if they answer that they have learned the equation
of state, and they have learned to use LoggerPro[The data collection soft-
ware], or maybe they say, that they do not know. But if you ask them
about control of variables, then I expect them to say yes straight away.
I expect so, yes. Also because I will tell them. If they do not know it is
because they have not listened.

Here Alice expects them to straight away talk about the familiarization of the equation of state. She also includes the use of the equipment, which she has not set as a purpose of the task, but a possible answer for the students. Alice explains how she will tell the students her intended learning outcomes, but she does not feel sure they will be able to replicate the purposes when I ask them. But if they are given clear hints, she expects them to know.

She was then asked if it is almost every time she makes the students aware of her intentions:

Alice You probably should do it more often. But you are so focused on the
content. Now you should learn about this, no we should learn how the a-
bomb works or something. So it is probably very fluctuating. It is probably
mostly when I am like... When it is something special, like where, that I
am very aware of what it precisely is about.

She again explains how this is difficult in two levels. First it is difficult to be aware of the intentions herself (because most often she will be focused on the content), and second it is also difficult to get around to say it. But she would like to do it more often, since she believes it makes a difference.

C.3.2 Burt - will the students know the purposes?

Burt expects only some of his students to be aware of his intentions, and he is fine with it. It is a task the students have to make out themselves, since his states his is going to make it fairly clear, but not very explicit about his intentions.

Burt Some of them will. Also because I am going to make it fairly clear what
it is we are trying to reach, what it is we are working with. But it is
not something everybody will understand on a higher level. And less can
maybe also do it.[...]

Burt But like, to be very explicit and articulated about it, that is probably...,
no, that might be too much to ask.

When talking to Burt, he places focus on two of his intend learning outcomes, namely the nature of science and to some extent the concept of conservation, leaving the unit system and the theory building behind.

Burt But I both hope and think, they will say something about how they have
more knowledge of energy and energy conservation through the labwork.

And maybe also say something about which things play a role in praxis and make them see how the simple energy conservation they calculate on is more complex.

He expects the students to focus on the concepts of energy and energy conservation, and maybe about the nature of science, as explained by ‘which things play a role in praxis’.

C.3.3 Charles - will the students know the purposes?

Charles here chooses not to refer back to his intended learning outcomes of probability, harmfulness and handling of data:

Charles I think they can. Well, of course, yes, but I think I normally point out what is important at this stage. For instance maybe it is not so important to prove the law of radioactive decay, but more like what to use it for.

He instead talks about not so much the mathematical proof of the law of radioactive decays, but instead the ability to use it. Charles states here how he normally points out what is important for the given activity, indicating this is also what will happen here.

C.3.4 Derek - will the students know the purposes?

Since we are not talking about the purpose of the specific labwork activities, which Derek is to do, then this question does not really make sense. But we talk about how he will be able to detect if the students know his intentions.

Derek . . . when I can see they starts to talk and act in a way in the physics classes, which are very independent and where they have learned and acquired these apparatus or acquired these tools in physics and can talk about it [then he known they learned what he intended]. Or when meeting a new natural phenomenon and are able to explain it by previously taught theories, or at least reject some explanations based on theory. I find it . . . when such a thing occur then I know they are starting to use this the scientific way of thinking more actively and can use it on some things we have not discussed directly before.

C.3.5 Comparison - will the students know the purposes?

Alice is reluctant to promise me her students will be able to replicate her intentions, even though she is going to tell is clearly to her students. She though expects them to be able to recognize the purpose, if presented to them. When talking about this, she talks about only two of her three intentions, namely the equation of state and the control of variables, leaving the graphical data treatment behind, exchanged with a focus on the apparatus.

Burt expects the cleaver students to be aware of his intentions, since the students can only be aware of the intended learning outcome, if they are reaching the learning outcome.

Charles is sure the students will be aware of his intentions, since he will let them know. But he now refers back to some other intentions then though he previously gave, indicating he is not completely aware of his intended learning outcomes of the labwork task.

Derek are often able to detect if his students learn what he intents them to learn from the way they talk and act. But we are not talking about the specific labwork activities, since we are together planning them.

D The case teachers' labguides

In this appendix labguides from the four case teachers are found.

Alice's labguide is about the state of matter (the ideal gas law), where four experiments are to be done:

- Determination of the molar volume of air
- p as a function of V
- p as a function of n
- V as a function of T

Burt's labguide concerns a labwork on an air track, where the change in kinetic and potential energy of the system of a cart attached to a pull weight are compared, in order to verify the conservation of the mechanical energy of the system.

Charles runs two labwork activities: A measurement of the halfwidth of aluminium and lead in relation to gamma radiation and a measurement of the halftime of a Barium isotope. For the latter I was granted permission to include a small section about random and systematic uncertainties.

I have also written a introductory paper to Charles about uncertainties, which I intended him to take off from in his introduction.

Derek runs the same two labwork activities as Charles. First is the halftime measurement for the same Barium isotope. The latter is the halfwidth measurement for lead in relation to gamma radiation. For the latter, I was granted permission to include a single line emphasizing the purpose of the labwork was also to engage with the concept of random and systematic uncertainties. This was used along with the introductory paper about uncertainties, which the students got copies of.

D.1 Alice's labguide

Box D.1 Alice's labguide, page 1 (own translation).

Experimental verification of the equation of state of an ideal gas

Control of variables

The equation of state

$$p \cdot V = n \cdot R \cdot T$$

Is a classic example of a connection (equation), containing several variable quantities. If the equation is to be verified, it is of no use to change everything at the same time. The variable quantities should be *controlled* in such a way, that only two quantities are varied, while the rest is kept constant.

To verify all connections, several experimental sequences must be done, each with only two variables.

As an example we look at an experiment which we did last year with the purpose of investigating the connection between pressure and temperature. The gas (regular air) was concealed in a glass container and heated in a water bath. What was varied and what was constant?

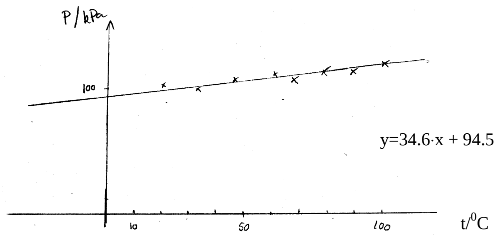
p: variable (The pressure increased while heated and was measured occasionally)

V: constant. (The volume of the gas was at all time equal to the volume of the class container)

n: constant. (The system was closed letting no air in or out)

T: variable. (The temperature was equal to the temperature of the water bath)

Graphical data treatment



The results are shown in a coordinate system with the two variable quantities along the axes. Along the x-axis the quantity to be varied is found (in the example above is it the temperature) and along

1

Box D.2 Alice's labguide, page 2 (own translation).

the y-axis is it the quantity which is effected by the change (in the example: pressure): pressure as a function of the temperature.
The graph displays that p is linearly dependent of the temperature with the equation:

$$p = 34,6 \frac{\text{kPa}}{{}^{0}\text{C}} \cdot t + 94,5\ \text{kPa}$$

If the zero of the temperature is moved to the point where the line is meeting the pressure-axis (Kelvin scale) (*T=0* when *p=0*) you get:

$$p = 34,6 \frac{\text{kPa}}{\text{K}} \cdot T$$

Comparison with the theory

When the two variables are chosen, it is reasonable to rewrite the theoretical formulation, so all the constants are placed together:

$$p \cdot V = n \cdot R \cdot T \Leftrightarrow$$
$$p = \left(\frac{n \cdot R}{V} \right) \cdot T$$

From this is seen that the pressure is proportional with the temperature (measured in Kelvin). The constant of proportionality (the slope of the graph) is given by the constant quantities *n*, *R*, and *V*. When the slope of the graph is evaluated it is therefore very important, that you have remembered to note the value of the constant quantities.

Task

You are to do an experiment which shows the connection between pressure (*p*) and volume (*V*). You have a plastic syringe and a pressure meter at your disposal.

a) Which quantities should be held constant and which is to be varied?
b) How would a measuring scheme display?
c) What are the values of the constant quantities?

2

Box D.3 Alice's labguide, page 3 (own translation).

Guide for the experiment

Each team should do each of the three experiments with the following set of variable quantities:

1. *p* as a function of *V*
2. *p* as a function of *n*
3. *V* as a function of *t*

p measures with a pressure sensor connected to the labpro and the program **labpro** (a guide is placed at the setup).

V is measured by directly reading of the plastic syringe or the pipette.
t measures with a regular thermometer.

n is found by the volume of the gas at room pressure and temperature (se below):

$$n = \frac{V}{V_M}$$

where V_M is the molar volume: in other words the volume of 1 mole of gas at room temperature and the barometric pressure.[1].

PROGRAM:

	First labwork module		Second labwork module	
Team 1 + 2	1	2	3	0
Team 3 + 4	1	2	0	3
Team 4 + 5	3	0	1	2
Team 5 + 6	0	3	1	2

The numbers indicate the experimental task number.

[1] The pressure in the room is given by the barometric pressure. The barometric pressure is alternating around 1013 hPa, depending on the weather.

3

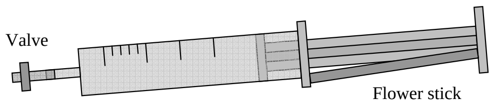
Box D.4 Alice's labguide, page 4 (own translation).

0: **Introductory experiment: The molar volume of air at room temperature and barometric pressure**

Purpose: to determine the volume of 1 mole of gas at room temperature and barometric pressure

If, e.g. 50 mL of air is concealed in the syringe this equals a specific amount of matter *n*. To be able to convert from volume of gas to amount of matter of it is useful to know the molar volume (the volume of one mole of gas at barometric pressure and room temperature)

The piston in the syringe is pressed all the way down to the bottom and the vent is closed. The piston is dragged back to a large volume (like 60 mL) and a flower stick or something like it is squeezed in such the piston does not return. Now weigh the syringe on a milligram precise weight. The vent is opened to the syringe is filled with air.
Weigh the syringe with the vent and the flower stick, and you will find the mass has increased.



The increase is equal to the mass of the air, which you put in the syringe. From the volume and the mass of the air you are to calculate the density of the air ρ at room pressure and room temperature.

Resultants:

Volume V = …………….

Mass with air m_1 = …………… Mass without air m_2 = …………….

Mass gain: m = …………….

Calculations:
The amount of matter in the syringe can now be determined from the mass gain *m*, the volume of the gas and the average molar mass of air: *M* = 28.97 g/mol.

Molar volume (volume pr. mole gas): $V_M = \frac{V}{n} = \frac{V}{m/M} = \frac{M \cdot V}{m}$

- V_M = ………………….

4

Box D.5 Alice's labguide, page 5 (own translation).

This number should be close to 24.1 L/mol. If the deviation is large, you should use 24.1 L/mol in the following.

If the temperature is not 20°C and/or the barometric pressure is not 1013 hPa theoretically the molar volume will deviated from 24.1 L/mol.

Labwork task 1 and 2:

Control:
It the power supply to the labpro connected and turned on?
Is the labpro connected to the PC via a USB port?
Is the pressure sensor connected to the labpro?

Start the program 'loggerpro' (icon on the desktop) and adjust the program. (See guide by the PC)

- Notes: Room temperature: Barometric pressure:

***1: p as a function of V* (Boyle-Mariotte's law)**
Do the experiment with a small plastic syringe. Place the piston approximately in the middle of the syringe and note the volume and the temperature in the room. Place the syringe directly on the pressure sensor.
Vary the volume and measure the pressure.

Resultants:

- The volume of the gas concealed in the syringe at room temperature and barometric pressure is: V_0 = …………

Data treatment:
A fit curve is easily done by the software program 'loggerpro'.
A source of error could bet hat a small volume of gas is trapped in the pressure meter. If the graph does not fit you can try to add e.g. 1 mL to the volume in the fit equation. (Ask if you do not know how to do it in the software program).

5

Box D.6 Alice's labguide, page 6 (own translation).

2: p as a function of n

- Choose a constant volume with the piston approximately in the middle of the syringe: V_o = ………….

Remove the syringe from the pressure sensor and push or pull the piston (to vary the amount of matter of air in the syringe)
Instead of the amount of matter (*n*) the volume of the gas is used <u>at room pressure and temperature</u> as the x-value. We can do that because there is the proportionality: $n = \frac{V}{V_M}$
Place the syringe on the pressure sensor and push/pull the piston to the chosen constant volume. MEASURE (*V* and *p*).

Results:
Room temperature: Pressure: *B* =

Chosen constant volume V_{const} = ………………

Data treatment:
The fit curve is done in the program 'loggerpro'.
Again, the air in the sensor can be a possible source of error, which you can examine in the same way as in labwork task 1.

3: V as a function of *t*

Apparatus: Cut open milk container with is (to be picked up in the freezer), pipette with paraffin wax, thermometer, electric kettle.

The experiment is done on the trapped air in paraffin wax in a pipette (open at the top). Put water in the ice and wait. The temperature in the mixture of ice and water stabilises pr. definition at 0^0C. Place the pipette in the water and read of the volume of the air bobble. It has to be done VERY precisely.
The temperature of the water is to be varied and the volume is read off again. Stop at temperatures around 50^0C (At higher temperatures the measurement become bad, probably because the paraffin wax evaporates and thereby increase the amount of matter.

Resultants:
- Room temperature: Barometric pressure =

Data treatment:
Do a graph of *V* as a function of *t* and draw the fit curve.

6

Box D.7 Alice's labguide, page 7 (own translation).

The slope can be compared with the expression on page 2, but the intersection with the temperature axis should be displaced with 273.15 degrees.

Report

This time only one report is handed in pr. group (group report).
Hand in data: 5th of January (preferably in my mailbox or else electronically)

Divide the report in the different tasks (4 tasks).

It is allowed to only show the measuring results and calculations of the introductory experiment. For labwork tasks 1 to 3 the report should contain:

- Purpose
- Short theory (rewrite the equation of state so it is easy to compare the graph)
- Results
- Data treatment
- Conclusion

7

D.2 Burt's labguide

Box D.8 Burt's labguide, page 1 (own translation).

Labwork with report

19. Conservation of mechanical energy

We are to investigate the transformation between potential and kinetic energy in movement on an air track.

Setup: For the exercise an air track with an appertaining easy gliding pulley in one end is used. For the track a special cart is used with load weights and some pull weights. As a clock a counter is used, which is connected to a photo cell with a light source. The counter is set to register the pass time Δt , where the light beam in the photo cell is shut off by the tab of the cart.

The experiment: First the air track is adjusted to be completely horizontal. The masses of the cart, the load weights, and the pull weights are determined. The length of the cart's tab Δs is also to be measured.

The weight of the cart (including the load weights) is called m_1, the weight of the used pull weight is called m_2. The path distance is called *s*. The path distance is the length from the position where the movement starts to the photo cell.

Each of the following single experiments is done 3 times, and of the time measurements Δt_1, Δt_2 and Δt_3 the average Δt is found.

Six different experiments are done using two different pull weights (e.g. 20 g and 40 g) and three different path distances (e.g. 30 cm, 60 cm and 90 cm).

Data treatment: For each experiment the gain in potential and kinetic energy is calculated. We apparently have

$$\Delta E_{pot} = -m_2 \cdot g \cdot s \qquad \text{and} \qquad \Delta E_{kin} = \frac{1}{2} \cdot m \cdot v^2$$

where *m* is the entire accelerated mass $m = m_1 + m_2$, and the speed is calculated by $v = \frac{\Delta s}{\Delta t}$.

Compare ΔE_{pot} and ΔE_{kin}. Is the mechanical energy conserved?

The report should contain: objective, drawing of the setup, scheme with the results, process of the results with a detailed calculation for on of the experimental series, comparison of ΔE_{pot} and ΔE_{kin}, sources of error, comments and if possible explanations of significant deviations, evaluation or conclusion.

Box D.9 Burt's labguide, page 2 (own translation).

Measuring scheme for exercise 19

Δs =

m_1	m_2	s	Δt_1	Δt_2	Δt_3	Δt	v	m	ΔE_{pot}	ΔE_{kin}

D.3 Introduction to random and systematic uncertainties

I have written a paper about random and systematic uncertainties to let Charles and Derek know my intentions with this intentions. They both hand out this paper to their students. Charles copies it on the back of the labguide which he hand out the day of the labwork activity. Derek makes his students read it as homework and use it as a basis for discussing random and systematic uncertainties some days before the halfwidth labwork.

Box D.10 My introduction to random and systematic uncertainties, which is used by both Charles and Derek

Introduction to errors and uncertainties:

Labwork activities in physics in not only for lets say determining the halfwidth of gamma radiation for aluminium plates. Even more important is it that the labwork itself and the report writing teach you a line of competencies, which are relevant both in the school discipline of physics, but also in other connections.

The labwork activity concerning the halftime of Barium gives you an opportunity to train a line of these competencies, but I wish to place focus on one of these, namely errors and uncertainties. I all of the previous labwork activities you have already been working with errors and uncertainties, but might not given it a thorough consideration.

Let us start with an example taken outside physics: Imagine being a traffic researcher wishing to determine the number of cars passing a specific road. You might place you near the road and count the number of cars passing. If you only count for one minute you will reach a quite imprecise picture of the number of passing cars. The number of cars pr. minute is random. Some minutes more cars pass by than others. Besides that it is of course also relevant when during the day you are counting the cars. There will probably pass by more cars at 4 pm than 4 am. There is also the possibility of you making a miscount.

Let us look at these kinds of errors and uncertainties. In the case where more cars pass by one minute than another, there can be several explanations. Maybe the cars have just stopped at a red light. This is a systematic error. If there is a red traffic light fewer cars pass by than when the traffic light is green. This error can be rectified in the set of data. If the red light and the green light is both lasting one minute, this can be taking into considerations when calculating the flow of cars. But also other reasons exist for not measuring the same number of cars each minute. People choose to leave their work at different times, which can not be foreseen. It is not correlated and therefore random. So it is a random error - and then again. There is a systematic error since more cars leave work at 4pm than 8am. Finally there is the possibility of you making a miscount or your stopwatch not being precise. These errors can both be random or systematic.

To sum up: in physics you work with two types of errors: *random and systematic errors*:
Random errors are an expression of uncertainties. These can show of by limited precision in the measuring equipment. You know random errors when measuring the same quantity and getting different results, even though you are measuring under the same conditions. Random errors can also emerge from randomness in the system, as it is the case for e.g. radioactive decays, which is unpredictable. Since every measured quantity in physics is encumbered with uncertainties it is important only to show of the result by the relevant number of significant digits (and if possibly an uncertainty if this is determined).
Systematic errors are regular inaccuracies in the system to be measured on, and the systematic errors change by a regular pattern when the measuring conditions are changed. You know systematic errors when measuring the same quantity several times and each time it is smaller than the table value. Then you have discussed which source of error causes this smaller value, in other works which source there exist for this systematic error.

All measured quantities are encumbered with errors and uncertainties. Therefore it does not make sense to state the length of the table is 2.34975839 metre when only having a carpenter's ruler to measure it. Not even when measuring it 100 times, and the average is 2.34975839 metre. The best way to determine the length of the table is to measure it out a number of times, find the average and deviation and then let the answer be e.g. 234 cm +/-2 cm or 234 cm +/- 0,9%.

D.4 Charles' labguides

Box D.11 Charles's guide to the labwork about finding the half-thickness of lead and aluminium with a gamma source.

The purpose of the exercise

is to determine the half width of lead and aluminium with a gamma source.

Theory:

The intensity of radiation decays as an exponential function of the width of the lead layer.
$I = I_0 \cdot e^{-\mu x}$

Here I_0 is the intensity before the lead/aluminium, I is the intensity after a layer of x and u is the absorptions coefficient, which is a material and radiation energy dependent constant.

The half width is given by $x_{1/2} = \frac{\ln 2}{\mu}$

In this exercise we will measure the intensity as a function of the thickness of the lead layer, and from there determine $x_{1/2}$. All we need to know is that the intensity decays exponentially by the lead layer.

Half-width:

Setup:

Start by connecting the GM counter to the computer. Take a gamma source and set up the GM-tube as shown.

Count the background radiation in 60 seconds 3-5 times.

Then place the plates on by one. The widths of the plates measures and are to be noted.

After each measurement you place another plate and measure its width.

Draw a graph which shows the width of the plates on the x-axis and the number of counts on the y-axis.

Draw the same graph on logarithmic axes.

Determine from this the slope, u, and the half width $x_{1/2} = \frac{\ln 2}{\mu}$.

Box D.12 Charles's guide to the labwork about finding the half-life of Barium.

Labguide, halftime of Barium

Introduction

This labwork task focuses on the ability to understand and work with *errors and uncertainties* that are a general competency relevant both in and outside physics. In all earlier labwork tasks you have worked with errors and uncertainties, but you might not have given it thorough considerations.

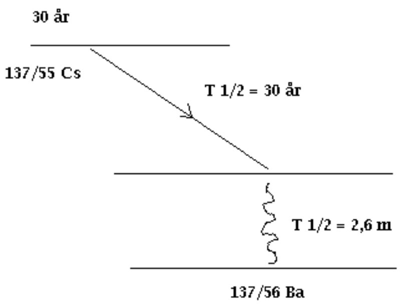
In physics you work with two types of errors: *random* and *systematic* errors: *Random errors* is an expression of uncertainties. These can occur by limited precision in the measuring devise. You know random errors when measuring the same quantity and reaching different results, even though you have not changed the conditions. Random errors can also occur by randomness in the system, like it is the case of radioactive decays, which you can not predict when, will happen. Since every measured quantity in physics is encumbered with uncertainties it is important to only state the result with the relevant number of significant digits (and possibly an uncertainties if determined).

Systematic errors are regular uncertainties in the system to be measured on, and the systematic errors change after a regular pattern, when the conditions of measuring are changed. You know systematic errors if you measure the same quantity repeatedly, and each time get a value below the expected table value. Then you have discussed which sources or error could cause this smaller value, in other words which sources there exist for this systematic error.

Purpose

The purpose of this labwork task is to find the halftime of $^{137}/_{56}$ Ba. In the task a $^{137}/_{55}$ Cs source is used. $^{137}/_{55}$ Cs decays through β^{-} radiation to an exited state of $^{137}/_{56}$ Ba. The half-time for the $^{137}/_{55}$ Cs decay is approximately 30 years.

The exited state in $^{137}/_{56}$ Ba is named with the insertion m because of its meta-stability since its halftime is relatively long compared to that of the decay to the ground state in $^{137}/_{56}$ Ba. The decay happens by radiation of gamma.



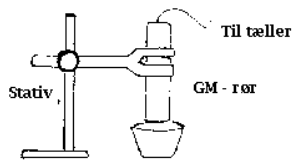
Execution:

The background radiation is determined by measurements over a 5 minutes period of time. Thereafter the counter is adjusted to give message every 10 seconds. It should continue until the count number is close to the background count number.

$^{137}/_{56}$ Ba is made by the so-called ion trading. An ion trader is used, which pushes an acid NaCl dissolution through a plastic container containing $^{137}/_{55}$ Cs. The dissolution is pressed through the ion trader with a speed of 2-3 droplets pr. second. The liquid is collected in a small bowl.

After this the bowl is fast placed below the GM-tube with a very small distance between the surface of the liquid and the GM-tube. The counting is to be started fast.

When only the background radiation is left the counter is stopped and all numbers are typed into an excel spreadsheet, where you subtract the background radiation from all numbers.



Used equipment:

1 Geiger-Müller tube
1 counter
1 ion trader
1 acid NaCl dissolution
1 little bowl

D.5 Derek's labguides

Box D.13 Derek's labguide for the half-time exercise.

Halftime of Barium-137*

The aim of the experiment

We wish to determine the intensity of the background radiation I_{backgr} and determine the halftime of Ba-137*. The radioactive agent is called Caesium (Cs). It decays in this way:

$$^{137}_{55}\mathrm{Cs} \rightarrow ^{0}_{-1}\mathrm{e} + ^{137}_{56}\mathrm{Ba}^* \qquad \text{and on...} \qquad ^{137}_{56}\mathrm{Ba}^* \rightarrow ^{137}_{56}\mathrm{Ba} + ^{0}_{0}\gamma$$

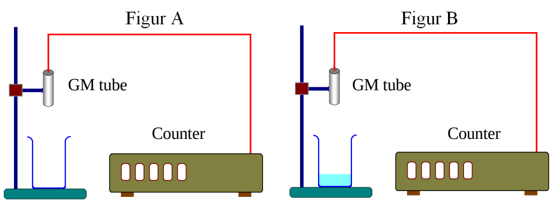
where * indicates the nucleus is in a so called *isomer state*, that is a state where the nucleus holds to much energy. We are to determine the halftime of this isomer state by use of a *mini generator*. A leaching with an infusion liquid (dilute hydrochloric acid with dissolved NaCl) affects the daughter nuclide (the Ba*-nuclei) are washed out of the mini generator and leaves only the mother nuclei (the Cs-nuclei) inside the mini generator. After the leaching we only have the Ba*-nuclei left, and we can therefore determine their halftime.

Background radiation

With the setup seen in figure A we count the background radiation in three minutes. From this we can calculate I_{backgr} as the number of counts pr. 10 seconds. I_{backgr} is in other words the number of counts when no source is in front of the counter or not.

Main measurement

The only difference from figure A to figure B is the liquid in the cup. Set the counter to count continuously in 10 second intervals (please ask!). Pour the liquid with Ba-137* into the cup (please ask again!). Continue to note the count numbers for approx. 5 minutes. We read out a count number for each 10 second interval.



We rectify the count numbers from the background radiation by use of this formula:

$$I_{rectified} = I - I_{backgr}$$

In Excel we display $I_{rectified}$ as a function of time and draw the best fit through the points by use of exponential regression. From this graph we can read out and calculate the halftime $\tau_{½}$. Finally we compare it with the table value of 153 s, and calculate the deviation (percent wise).

Box D.14 Derek's labguide for the half-width exercise.

Halfwidth of gamma radiation

The purpose of the experiment is to determine the background radiation N_{backgr} and to determine the needed width of lead to half the γ-radiation from Barium-137*.

Background radiation

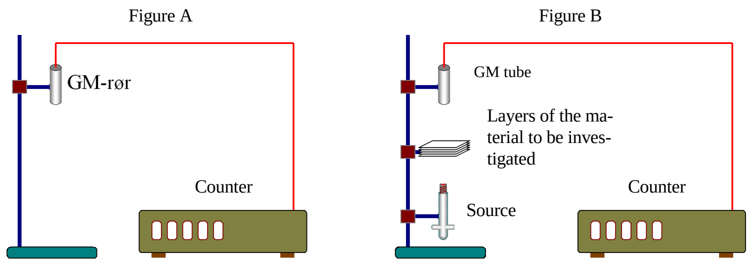
With the setup of figure A we count the background radiation in three minutes. From this we calculate N_{backgr} as the number of counts pr. minute. N_{backgr} is then the number of counts when no source is in front of the counter.

Main measurement

With the setup of figure B we count in one minute for each new layer of material placed between the source and the counter tube. We calculate $N_{rectitied}$ subtracted the background radiation by:

$$N_{rectified} = N - N_{backgr}$$

$N_{rectified}$ is calculated and is in Excel displayed as a function of the width of the layer. We find the halfwidth of *this type of* γ-radiation by exponential regression.



Find in literature the table value of the halfwidth of lead (for γ-radiation). Compare the result for lead with the table value and give the percent wise deviation.

Estimate and explain the random and systematic uncertainties of the experiment.

E Typical series of labwork activities

In this appendix additional information used to perform the linking between specific labwork activities and sub-domains of the procedural skills are found.

First is a combined table of the sub-domains of the procedural skills for an overview, and second is the labguides, which form the basis of the linking.

E.1 Typical labwork activities and their connection to the core content of curriculum

Table E.1 Most often found physics labwork activities done in the first year of the Gymnasium and their connection to the core content found in the curriculum.

Core content	*Typical labwork activities*
Energy	
• Description of energy and energy transformation, including power and efficiency. • Examples of types of energy and a quantitative treatment of the transfer between at least two types of energy.	1. Efficiency of e.g. coffee maker 2. Heat capacity (solids) 3. Heat capacity of water 4. The specific melting heat of ice 5. The specific evaporation heat of water
Sound and light	
• Basic properties: wave length, frequency and speed. • Experimental determination of wave length. • Physical properties of sound and light and their connection to sensory perception.	1. Standing waves in tube / speed of sound 2. Optical grating/distance of furrow of cd
Supplementary content	
	1. Density of solids or liquids 2. Pendulum

Table E.2 Most often found physics labwork activities done in the second year of the Gymnasium and their connection to the core content found in the curriculum.

Core content	*Typical labwork activities*
Electric circuits	
• Simple electric circuits with stationary currents, described by current, voltage, resistance and energy transformation	1. Electric resistance (Ohm's law) 2. Joule's law
Waves	
• Basic properties: wave length, frequency, speed and interference • Sound and light as examples of waves • The electromagnetic spectra	1. Standing waves on string
Quantum physics	
• The structure of atoms and nuclei • Emission and absorption of radiation in atomic systems, spectra • Radioactivity, including types of decays, activity and the law of decay	1. Spectral analysis 2. Halfwidth (radioactivity) 3. Halftime (radioactivity)
Mechanics	
• Kinematic description of motion in one dimension • Concept of force, including gravity, pressure and buoyancy • Newtonian laws on motion in one dimension	1. Free fall (ball) 2. Friction (incline or drag) 3. Air track (energy cons., Newton 2)
Supplementary content	
	1. Ideal gas

Table E.3 Most often found physics labwork activities done in the third year of the Gymnasium and their connection to the core content found in the curriculum.

Core content	*Typical labwork activities*
Mechanics	
• Concept of force and laws of Newton, including pressure, buoyancy and friction • Motion in one and two dimensions, including projectile motion and uniform circular motion • Conservation of momentum, including elastic and inelastic collision	1. Air resistance with cake tins 2. Projectile motion 3. Momentum 4. Uniform circular motion

E.2 Procedural skills domain - overview

Table E.4 Overview of the sub-skills of the procedural domain.

Associated with design	
Variable identification	Understanding the idea of a variable and identifying the relevant variable to change (the independent variable) and to measure, or assess if qualitative (the dependent variable)
Fair test	Understanding the structure of the fair test in terms of controlling the necessary variables and its importance in relation to the validity of any resulting evidence
Sample size	Understanding the significance of an appropriate sample size to allow, for instance, for probability or biological variation
Variable types	Understanding the distinction between categoric, discrete, continuous and derived variables and how they link to different graph types
Associated with measurement	
Relative scale	Understanding the need to choose sensible values for quantities so that resulting measurements will be meaningful. For instance, a large quantity of chemicals in a small quantity of water causing saturation, will lead to difficulty in differentiating the dissolving times of different chemicals
Range and intervals	Understanding the need to choose sensible range of values of the variables within the task so that the resulting line graph consist of values which are spread sufficiently widely and reasonable spaced out so that the 'whole' pattern can be seen. A suitable number of readings are therefore also subsumed in this concept
Choice of instrument	Understanding the relationship between the choice of instrument and the required scale, range of reading required, and their interval (spread) and accuracy
Repeatability	Understanding that the inherent variability in any physical measurement requires a consideration of the need for repeats, if necessary, to give reliable data
Accuracy	Understanding the appropriate degree of accuracy that is required to provide reliable data which will allow a meaningful interpretation
Uncertainties	Understanding the difference between systematic and random uncertainties, and how they affect the accuracy. Understanding how systematic uncertainties cannot be reduced by repeating the same experiment
Associated with data handling	
Tables	Understanding that tables are more than ways of presenting data after they have been collected. They can be used as ways of organizing the design and subsequent data collection and analysis in advance of the whole experiment
Graph type	Understanding that there is a close link between graphical representations and the type of variable they are to represent. For example, a categoric independent variable such as surface, cannot be displayed sensibly in a line graph. The behaviour of a continuous variable, on the other hand, is best shown in a line graph
Patterns	Understanding that patterns represent the behaviour of variables and that they can be seen in tables and graphs
Multivariate data	Understanding the nature of multivariate data and how particular variables within those data can be held constant to discover the effect of one variable on another
Units	Understanding and being able to include units in the data handling
Equation translation	Being able to translate between the mathematical expression gained from a fit procedure to an equation containing the relevant physics quantities (including units)
Associated with the evaluation of the complete task	
Uncertainties and errors	Understanding the effect of the uncertainties embedded in the measurements on the reliability of the results. Understanding the accuracy of the found results in relation to uncertainties. Understanding the concept of significant digits
Reliability	Understanding the implications of the measurement strategy for the reliability of the resulting data; can the data be believed?
Validity	Understanding the implications of the design of the validity of the resulting data; an overall view of the task to check that it can answer the question
Associated with the communication of the complete task	
Communication	Understanding how to communicate experimental findings

E.3 Analysis of common labguides

In this appendix the labguides corresponding to the most often used labwork activities are analyzed in relation to the sub-skills of the procedural domain.

E.3.1 Specific labwork activities and their specific purposes (C-level)

First the nine labwork activities determined for the C-level are described and then analyzed in relation to the sub-categories of the procedural skills domain.

Density of solids or liquids

The labwork is described as having a four-fold aim: (1) to learn how to collect measurements and gain results, (2) to handle measurements in a graphical way, (3) become confident with the concepts of proportionality and linearity, and (4) to determine the density of alcohol. A copy of the labguide can be found at figure E.1 and E.2. This labwork is described as introductory.

The labwork is done by placing a measuring jug on a weight, and determine the mass without alcohol. Then a small amount of alcohol is poured into the jug and the mass and volume are determined. The process is repeated a number of times.

For the data treatment, three suggestions are made. Firstly, the density is calculated as the measured mass subtracted the mass of the jug divided by the volume for each measurement, and finally the average is found. Secondly, the measured mass subtracted the jug mass is plotted against the volume. The density is found by a best proportional fit. Thirdly, the measured mass is plotted against the volume, and the density is found by a best linear fit. The results of the three methods are compared to each other and a table value, and the percentage-wise deviation should be calculated. Finally the students are asked to account for the sources of error.

As for the sub-categories of the procedural skills, for those associated with design, the labwork might serve the purpose of *variable identification*, since the students is provided with the opportunity of recognizing the independent (volume) and dependent variable (mass), and to some extent understanding how they can interchange roles, since they are bound together with a physical bond of the density value. *Fair test* is not relevant, since only the named variables have the opportunity of coming into play. *Sample size* could be touched upon when deciding upon the number of experiments, understood as how much alcohol to add at a time. *Variable types* are most likely not addressed in this labwork.

For those associated with measurement, the *relative scale* does not make sense for this labwork. *Range and intervals* are on the other hand relevant, since the students are to determine which values of the volume, they are to measure upon. Since the total volume of the jug will set a faster limit on the

Figure E.1 Labguide for density of solids or liquids, page 1 of 2.

Densitet for sprit

Formålet med denne øvelse er

- du skal lære at optage måleresultater
- lære at behandle måleresultater grafisk
- blive fortrolig med begreberne proportionalitet og linearitet
- bestemme sprits densitet

Udstyr og kemikalier
Måleglas, 100 mL
Massemåler
Sprit

Teori
Et stofs densitet er defineret som

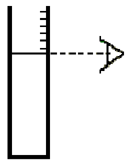
densitet = masse pr. rumfang

Masse betegnes m, og rumfanget V. Densiteten betegnes r. Med andre ord

$$\rho = m / V$$

SI-enheden for densitet er kg/m^3. Vi vil dog måle massen i g og rumfanget i mL, og dermed angive densiteten i g/mL.

Fremgangsmåde



Mål først massen af det tomme og tørre måleglas. Dets masse betegnes m0.. Derefter hældes ca.: 10 mL sprit i måleglasset. Prøv ikke på at ramme præcist 10,0 mL. Det viser sig nemlig at være sværere at ramme en målestreg præcist end at aflæse præcist. Pas på at der ikke kommer sprit på måleglassets sider, da disse dråber jo ikke vil blive aflæst i spritten rumfang. Sprittens rumfang aflæses mest præcist ved at aflæse, som vist på figuren.Derefter vejes måleglas med sprit. Denne masse kaldes m_s . Resultaterne føres ind i skemaet. Der hældes yderligere ca. 10 mL sprit i måleglasset, og m_s og V aflæses igen. Også disse værdier føres ind i skemaet. Fortsæt således, idet du efter hver måling tilsætter ca. 10 mL sprit og aflæser m_s og V. Fortsæt indtil du har 7-9 målinger.
Når forsøgsrækken er endt, skal du hælde spritten tilbage i beholderen.

Forsøgsresultater
Indføjes i et skema, som det følgende:

Måleglassets masse m_0 = g				
Forsøg nr	V/mL	m_s/g	m/g	ρ i g/mL

Behandling af forsøgsresultater
A. Beregning af densiteten
Nu kan skemaet gøres færdigt, idet massen af spritten m i det enkelte forsøg er $m = m_s - m_0$

Figure E.2 Labguide for density of solids or liquids, page 2 of 2.

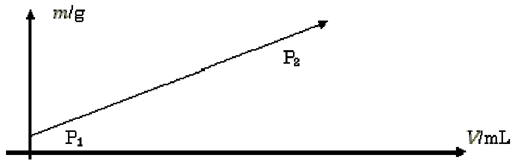
Herefter kan densiteten r beregnes i hvert enkelt forsøg. Desuden beregnes gennemsnittet af ρ-værdierne, og denne middelværdi sammenlignes med tabelværdien for sprits densitet. Find den i databogen.
Udregn også afvigelsen mellem $\rho_{gennemsnit}$ og ρ_{tabel} i procent.

B. Grafisk bestemmelse af densiteten. 1. metode

Da ρ = *m/V*, må det gælde, at *m* = ρ · *V*. Hvis du derfor afbilder de målte værdier af m som funktion af de målte *V*-værdier i et (*V*,*m*)-koordinatsystem, skulle du gerne få en ret linie gennem (0,0), hvis hældningskoefficient er r. Se model for grafen side 2.
Husk at sætte benævnelse på akserne og vælg en inddeling på disse, så millimeterpapiret udnyttes fuldt ud. Marker de afsatte punkter tydeligt enten med et 5 eller med en m. De afsatte punkter vil sikkert ikke ligge præcist på en ret linie, men så skal du tegne den bedst mulige rette linie mellem punkterne.
Beregn liniens hældningskoefficient ud fra to punkter P_1 og P_2. Husk at vælge punkter der ligger langt fra hinanden. Det gør usikkerheden mindre, når intervallerne bliver store. Vælg punkter, der ligger på linien, aflæs aldrig målesæt fra skemaet.
Sammenlign rgrafisk med rtabel og udregn afvigelsen i procent. Udregn også afvigelsen mellem $\rho_{grafisk}$ og $\rho_{gennemsnit}$ i procent.
For at vise, hvordan de tre værdier ligger i forhold til hinanden, er det en god ide at afbilde dem på en tallinie.

C. Grafisk bestemmelse af densiteten. 2. metode

Herefter skal du prøve at afbilde m_s som funktion af *V*. Det skulle også gerne give en ret linie. Forslag til graf:



Spørgsmål:
Hvorfor går denne rette linie ikke gennem (0,0)? I hvilket punkt bør grafen skære 2.-aksen? Hvad bliver forskriften for denne linie?

Generelt
Til sidst kan du komme ind på hvilke fejlkilder, der er ved forsøget - også selv om dine resultater ligger tæt på tabelværdien. Forklar også, hvordan de nævnte fejlkilder vil påvirke forsøgsresultatet.

Rapporten
Læreren vil fortælle dig, hvordan du skal udforme din rapport.

measuring interval than the weight, along with the fact that the accuracy of the jug scale and weight will not set an unacceptable limit to the density measure accuracy, issues related to the *choice of instrument* will most likely not come up for this labwork, but the labwork holds the potential. *Repeatability* is not addressable for this procedure. As for the case of *choice of instrument*, the issues of *accuracy* and *uncertainties* could be brought up, but are in this labguide not addressed.

For the case of those associated with the data handling, *tables* are addressed especially for the first data treatment. As *variable types* were not addresses, so is neither *graph types*. *Patterns* are of great significance in relation to both proportionality and linearity. The *equation translation* is also included, but the labguide takes care of the *units* part. As was the case of the *fair test*, *multivariate data* are not addressed.

For those associated with the evaluation of the complete task, the *reliability* could be is included. The students are asked to account for their sources of errors, also if their data is close to the table value, placing some emphasis on *uncertainties and errors*. The *validity* is not brought up.

As the labwork leads on to a report, the communication skills are included. This will be the case for all of the following labwork activities, and I will not bother to write it for the rest.

Pendulum

The purpose of the labwork - as described in the labguide - is to investigate how the period of a pendulum depends on the mass of the oscillating weight, the length of the pendulum and the amplitude. As was also the case of the density labwork, this is described as an introductory labwork. See figure E.3 for a copy of the labguide.

The labwork is done by placing a small, heavy weight suspended by two strings to ensure a stabile one-dimensional oscillation. The period of the pendulum is found by measuring 20 oscillations in order to decrease the uncertainty. Three measuring series are to be done: (1) Varying the amplitude (but though not measuring the amplitude size) and keeping the mass and length constant. (2) Varying the length and keeping the mass constant. (3) Varying the mass and keeping the length constant.

For the first measurement no data handling is intended, since it is expected the students will see how the period is independent of the amplitude. For the second measuring series, the period is to be plotted against the length, and the students are asked to conclude on the relation between the period and the length. For the third measurement series, the relation between the period and the mass of the weight are to be determined in a non-declared way. As a conclusion, the students are asked to construct an equation to express the connection between the period and the three variables.

Figure E.3 Labguide for pendulum, page 1 of 1.

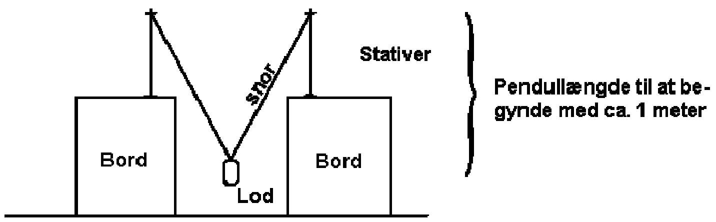
Svingningstid af et pendul

Indledende journaløvelse til 1g

Formålet med øvelsen er at undersøge, hvordan svingningstiden af et pendul afhænger af det svingende lods masse, pendullængden og udsvingets størrelse (amplituden).

Der anvendes et lille, tungt lod, som ophænges "bifilart", d.v.s. i to tråde. På denne måde opnår man, at pendulet kan svinge stabilt uden at svinge på tværs af den ønskede retning.

Pendulets masse kaldes *M*, længden *L* og svingningstiden *T*.



I øvelsen måles pendulets svingningstid, som er den tid, der går fra pendulet er i yderstillingen og til det er tilbage i samme yderstilling. Det er tilrådeligt at bestemme svingningstiden for 20 hele svingninger, og derefter dividere med 20, da usikkerheden herved bliver mindre.

I skal lave tre måleserier:

1. Først holdes pendulets masse og længde fast, mens udsvingets størrelse varieres. Svingningstiden bestemmes for et antal forskellige udsving. Hvad viser forsøget - hvordan påvirkes svingningstiden af udsvingets størrelse?

2. Massen holdes stadig fast, men nu varieres pendullængden. Svingningstiden bestemmes . Tegn i et koordinatsystem T_2 som funktion af *L*. Hvad viser grafen?

3. Med fast pendullængde varieres pendulets masse (udskift loddet). Mål svingningstiden med forskellige lodder. Hvordan afhænger svingningstiden af loddets masse?

Som konklusion skal I prøve, om I ud fra jeres resultater kan konstruere en formel, der udtrykker forbindelsen mellem svingningstiden *T* og de tre variable *M*, *L* og udsvingets størrelse!

This labwork serves a number of procedural sub-skills. For those associated with design, *variable identification* is especially significant, since the students are asked to differentiate between the independent variable to alter, the controlled variable, and the dependent variable to measure. Also for this experiment, the independent and controlled variable swap roles during the experiments. This also plays in on *fair test* understanding. To be able to answer the questions posed for the second and third measuring series, the students also need to be able to understand the *sample size* and its relation to answering the questions. *Variable types* are not addressed.

For the case of those associated with measurement, only the *range and interval* comes into play, since this labwork builds upon an inductive idea, wherefore the students most likely will not engage in any type of discussion concerning *accuracy*, *repeatability* and *uncertainties*, as well as *relative scale* and *choice of instrument.*

For those associated with data handling, the sub-skills of *tables*, *patterns* and *multivariate data* come into play, but especially the latter two are relevant in relation to this labwork. The sub-skills of *units* and *equation translation* will most likely not be concerned, again due to a somehow theory-independent approach. Since the *variable types* are not addressed, neither is the *graph type.*

For the case of those associated with the evaluation of the task, in the labguide itself these types of skills are not addressed.

Heat capacity (solids)

The purpose of the labwork - as described in the labguide - is to determine the specific heat capacity of aluminium. A copy of the labguide can be found in at figure E.4-E.5.

The labwork is done by placing an aluminium block in boiling water to make sure the block is 100 degree Celsius. The block is then moved into a known amount of water in a calorimetric bowl with a known temperature. The final temperature is determined as the highest measured temperature. The experiment is repeated three times, and information is noted in the pre-printed table.

Based on the principle of energy conservation and the measured quantities (the mass of the water m_w, the mass of the aluminium block m_a, the mass of the inner piece of the calorimetric bowl m_{cb}, the initial temperature of the water T_i, and the final temperature of the water T_f) the specific heat capacity of aluminium c_a can be determined.

$$\begin{aligned} 0 &= \Delta E_a + \Delta E_w + \Delta E_{cb} \\ 0 &= m_a \cdot c_a \cdot (T_f - 100 \circ C) + m_w \cdot c_w \cdot (T_f - T_i) + m_{cb} \cdot c_{cb} \cdot (T_f - T_i) \end{aligned}$$

The specific heat capacities of the water c_w and the calorimetric bowl c_{cb} are

Figure E.4 Labguide for heat capacity (solids), page 1 of 2.

Aluminiums specifikke varmekapacitet

Øvelsens formål

Øvelsens formål er at bestemme aluminium specifikke varmekapacitet.

Teori

Ved et stofs specifikke varmekapacitet forstås den energimængde, der skal tilføres et kilogram af stoffet for at stoffets temperatur stiger 1K. SI-enheden for specifik varmekapacitet er J/(kgK).

Desuden arbejder vi med et isoleret system, d.v.s. et system der ikke udveksler stof og energi med omgivelserne. Ifølge *varmeteoriens første hovedsætning* er den samlede energi konstant i et isoleret system. Sagt på en anden måde, så er afgivet energi lig med modtaget energi indenfor det isolerede system.

Apparatur

Messingkalorimeter, termometer (100 °C, 0,1 °C), kogekedel, aluminiumslod.

Forsøgets udførelse

Først vejes lod $m_a$og indre kalorimeterskål ms med en nøjagtighed på 0,1g.

Derefter koges loddet sålænge, man kan regne med, at det har opnået det kogende vands temperatur, som kan sættes til t_{100} = 100 °C.

I mellemtiden blandes godt 300 mL koldt og varmt vand i et krus, så blandingens temperatur kommer til at ligge lige så langt under stuetemperatur, som man forventer at sluttemperaturen i kalorimeteret kommer til at ligge over stuetemperaturen. Dette vand hældes i den indre kalorimeterskål og vejes, mv. Der skal være ca. 300g vand.

Efter forsigtig omrøring med termometeret i kalorimeterskålen, måles begyndelsestemperaturen t_b i kalorimeterskålen. Termometeret tages op af skålen.

Herefter føres loddet hurtigt over i kalorimeteret, idet man dog støder det let mod bordet på vejen, for at få vanddråber på loddet af.

Der røres rundt i kalorimeteret, medens man holder øje med temperaturen. Når den er højest, aflæses sluttemperaturen t_s.

Forsøget laves mindst tre gange.

Figure E.5 Labguide for heat capacity (solids), page 2 of 2.

Behandling af måleresultater

Idet systemet er isoleret, er afgivet energi lig modtaget energi indenfor systemet. Den energi loddet afgiver, må derfor være lig med den energi vandet og kalorimeterskålen modtager.

Afgivet og modtaget energi kan beregnes ved

(1) $E = m \cdot c \cdot t$

Nu kan man så opstille følgende kalorimeterligning:

(2) Loddets afgivne energi = vandets modtagne energi + skålens modtagne energi

hvilket også kan skrives som

(3) $m_a c_a(t_{100} - t_s) = m_v c_v(t_s - t_b) + m_k c_k(t_s - t_b)$

hvor c_v er vandets specifikke varmekapacitet og c_k er messingskålens specifikke varmekapacitet.

Den eneste ukendte størrelse i formel (3) er da aluminiums specifikke varmekapacitet c_a.

Måleresultater

Stuetemperatur:

Messings specifikke varmekapacitet c_k:

Vands specifikke varmekapacitet c_v:

Loddets masse m_a kg			
Skålens masse i m_s/kg>			
Vandets masse m_v/kg			
Loddets starttemp. t_{100} /°C			
Begyndelsestemp. t_b /°C			
Sluttemperatur t_s /°C			
Aluminiums specifikke varmekapacitet / (J/(kgK))			

Gennemsnit af aluminiums specifikke varmekapacitet:

Tabelværdi for aluminiums specifikke varmekapacitet:

Afvigelse fra tabelværdi :

to be looked up in a data table. Based on this the specific heat capacity of aluminium is determined and compared to the table value.

For this labwork the *variable identification* is quite important, since a large number of quantities and variables are in play here, and it is not obvious from looking at the equation which role the specific heat capacity of the aluminium, water or the calorimetric bowl material holds. The three other concepts of evidence associated with design (*fair test*, *sample size* and *variable types*) are not addressed in this labwork.

For those associated with measurements, the *relative scale* ought to be addressed in relation to the amount of water to place in the calorimetric bowl - though in the labwork the water amount is dictated by the labguide. *Range and interval* are not relevant. The labguide talks about the *choice of instrument* in relation to the accuracy of the weight, but it is not addressed further in the data treatment. Since the labwork is to be repeated three times, discussion of the *repeatability* exists. *Accuracy* and *uncertainties* are not taken up.

For the case of those associated with data handling, only the skill of *units* is addressed, since the students needs to juggle between grams and kilograms, depending on the units of table values and the units measured on the weight. The rest of the data treatment is only about manipulating equations.

For the case of those concepts of evidence associated with evaluation, the students might be encouraged to discuss *uncertainties and errors*, especially if their results are far from the table value. The same thing occurs for the *reliability*, whereas the *validity* is not addressed.

Heat capacity of water

The purpose of the labwork - as described in the labguide - is to determine the specific heat capacity of water. This labwork is developed through the research project NORD-LAB. See figure E.6-E.7 for a copy.

E.3.2 Labguide for heat capacity of water

The labwork is done by placing a given amount of cold water in an electric kettle, measuring the temperature of the water, and then turning on the kettle on for a given period of time. The temperature is then measured. The experiment is repeated five times with different periods of turn-on time.

Since the energy is used to heat up both the kettle and the water, the labguide states that

$$\Delta E = m_w \cdot c_w \cdot \Delta T + C_{kettle} \cdot \Delta T \tag{E.1}$$

leading on to

$$\frac{\Delta E}{\Delta T} = c_w \cdot m_w + C_{kettle} \tag{E.2}$$

Figure E.6 Labguide for heat capacity of water, page 1 of 2.

Vands specifikke varmekapacitet bestemt med elkedel

Fremgangsmåde

Start med at veje elkedlen. Du skal derefter lave 5 små forsøg, se dataskemaet nedenfor.

I hvert forsøg skal du

- i et måleglas afmåle cirka den anførte vandmængde fra den *kolde* hane, komme vandet i den tomme kedel, veje den påfyldte kedel, så du kan finde vandets masse, m_v. Husk at sætte låget på før hver vejning.
- sætte elkedlens stik i energimeteret — men tænd ikke ved elkedlens kontakt endnu.
- omrøre vandet grundigt med termometeret — afvent at vandets temperatur ikke ændrer sig — og aflæs vandets starttemperatur, T_b.
- starte et stopur og trykke på elkedlens kontakt på samme tid.
- slukke ved elkedlens kontakt, når den anførte tid - se dataskemaet - er forløbet.
- røre rundt i vandet med termometeret og aflæse vandets sluttemperatur, T_s, når temperaturen ikke stiger mere. Herefter kan du beregne $\Delta T = T_s - T_b$.

Teori

Da den tilførte energi afsættes dels i vandet dels i kedlen, må der gælde, at

$$\Delta E = c_v \cdot m_v \cdot \Delta T + C_{kedel} \cdot \Delta T$$

Hvis vi dividerer på begge sider med ΔT, får vi

$$\frac{\Delta E}{\Delta T} = c_v \cdot m_v + C_{kedel}$$

En linje har i et koordinatsystem en ligning af formen $y = a \cdot x + b$. Ved sammenligning ses, at hvis du i et koordinatsystem afsætter dine måledata med m_v ud ad 1. aksen og $\Delta E / \Delta T$ ud ad 2. aksen, bør du få en ret linje med c_v som hældningskoefficient og C_{kedel} som skæring med 2. aksen.

Måledata

Forsøg	Vandmængde	m_v / kg	t / s	T_b / °C	T_s / °C	T / °C	ΔE / kJ	$\frac{\Delta E}{\Delta T} / \frac{kJ}{°C}$
1	ca. 400 mL		20					
2	ca. 700 mL		35					
3	ca.1000 mL		50					
4	ca. 1300 mL		65					
5	ca. 1600 mL		80					

Figure E.7 Labguide for heat capacity of water, page 2 of 2.

Databehandling

Tegn den bedste rette linje som graf for $\frac{\Delta E}{\Delta T} / \frac{\mathrm{kJ}}{\mathrm{C}}$ som funktion af m_v /kg, jf. teoriafsnittet. Bestem derefter c_v og C_{kedel} ud fra grafen. Databehandlingen kan ske med brug af grafpapir, direkte på grafregneren med brug af lineær regression — eller du kan tegne og anvende lineær regression i et regneark.

Fejlkilder

Forhold dig kritisk til målemetoden. Beskriv fejlkilder.

Vurdering

Anfør tabelværdien for c_v og sammenlign dit resultat med denne.

where c_w is the specific heat of water, m_w is the mass of the water and C_{kettle} is the heat capacity of the kettle. Since the energy added to the system is expected to be proportional to the turn-on period $\Delta E/\Delta T$ can be plotted against the mass of the water m_w, and should according to the equation display a linear graph, where c_w is the slope and C_{kettle} should be the intersection with the y-axis. By plotting the graph (manually or digitally), the specific heat capacity of water can be found and compared to a table value.

For the case of the concepts of evidence associated with design, it might be rather difficult to define the dependent and independent variables, since on the following data handling, the dependent variable (the final temperature) is combined with the independent variable of the energy consumption (or turn-on period). This is not directly addressed in the labguide, but addressed it could be an interesting case to clarify *variable identification.* This labwork could also be addressing the *fair test*, since in this labwork the students both alter the water amount and the energy consumption. This is though not discussed in the labguide. For the *sample size* the students are dictated the amount of water and the turn-on period, and therefore are not discussing this. For the case of *variable types*, the students could be discussing how the independent and dependent can be displayed in the graph.

For those associated with measurements, the *relative scale* and the *range and intervals* are taken care of by the measuring scheme dictating the water amount and the turn-on period, but could addressed if the labguide were reformulated. For the rest (*choice of instrument*, *repeatability*, *accuracy* and *uncertainties*), this labwork is not taken up these skills.

For those associated with data handling, actually all but the *multivariate data* come into play, though only to some extent for the *tables* and the *units.* But obviously the *graph types*, the *patterns* and the *equation translation* are addressed for this labwork.

The students are asked to critically discuss the measuring method, and to compare their results to a table value, wherefore the skills associated with evaluation are addressed, though only to a lower extent the *uncertainties and errors* skill and *validity.*

Specific melting heat of ice

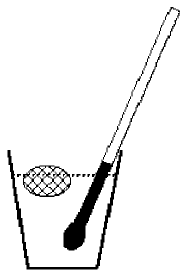
The purpose of the labwork - as described in the labguide - is to determine the specific melting heat of ice. A copy of the labguide can be found at figure E.8.

The labwork is done by placing hand-temperature water in a foam cup, measuring the temperature, and then placing ice cubes in the water. When all the ice has melted the temperature is again measured. On the basis of the masses of the water and the ice cubes, the specific melting heat of ice can be determined. Precautions have been made to make sure the ice has a temperature

Figure E.8 Labguide for specific melting heat of ice, page 1 of 1.

Smeltevarmen for is

1g journaløvelse / afleveringsopgave



Der skal bruges et (skum-)plastbæger, et termometer samt et par isterninger.

Fremgangsmåde:

Bægerets masse (uden indhold) bestemmes. Hæld lunkent vand (noget over stuetemperaturen) i bægeret. Vej bægeret med indhold, og bestem vandets masse m_v.

To isterninger lægges på en serviet. Når isen er begyndt at smelte (dens temperatur er da 0 ^oC) måles vandtes temperatur t_B. Isterningerne tørres af, og kommes over i bægeret. Når al isen er smeltet (rør rundt en gang imellem) måles sluttemperaturen t_S.

Vej bægeret med indhold, og bestem isens masse mis.

Måleresultater:

Masse af bæger	m_b =		____________ g
Masse af vand	m_v =	____________ g - m_b=	____________ g
Masse af is	m_{is} =	____________ g -____________ g=	____________ g
Begyndelsestemperatur	t_B =		____________ ^oC
Sluttemperatur =	t_S =		____________ ^oC

Opgave til skriftlig besvarelse:

Bestem isens specifikke smeltevarme *L*. Find værdien i databogen, og beregn %-afvigelsen i forhold til dit resultat.

Begrund, at det er fornuftigt at bestemme isens masse på den temmelig indirekte måde, det sker i øvelsen.

Gør rede for de væsentlige fejlkilder i forsøget.

of zero degrees Celsius.

Though not explained in the labguide, the principle behind the measurement is energy conservation:

$$
\begin{aligned}
0 &= \Delta E_{ice} + \Delta E_{water} \\
0 &= m_{ice} \cdot L_{ice} + m_{ice} \cdot c_w \cdot (T_f - 0°C) + m_w \cdot c_w \cdot (T_f - T_i)
\end{aligned}
$$

where m_{ice} is the mass of the ice, L_{ice} is the specific melting heat of ice, c_w is the specific heat capacity of water, T_i is the initial temperate of the water in the cup, and T_f is the final temperature of the water originally in the cup and the water from the melted ice. As seen the energy used to melt the ice, to heat the melted ice to the final temperature, and the energy gained from cooling the water are taken into account. In the labguide a pre-printed measuring scheme is done. The students are asked to determine the specific melting heat of water and compare it to the table value along with discussing why the specific melting heat has to be determined indirectly. Finally the students need to account for sources of error.

For this labwork, the *variable identification* is a significant skill, since a large number of quantities and variables are in play here, and it is not obvious from looking at the equation whether it is the specific heat capacity of water, the specific melting heat of ice or the final temperature of the mixture that is to be determined. On the other hand, the three other concepts of evidence associated with design (*fair test*, *sample size* and *variable types*) are not addressed in this labwork.

For those associated with measurements, the *relative scale* ought to be addressed in relation to the amount and temperature of water to place in the foam cup - though in the labwork the water temperature is dictated by the labguide. The skills of *range and intervals* are not touched upon, since only one measurement point is taken. The same thing goes with the rest of the skills associated with measurement (*choice of instrument*, *repeatability*, *accuracy* and *uncertainties*).

For the case of those associated with data handling, only the skill of *units* is addressed, since the students needs to juggle between grams and kilograms, depending on the *units* of table values and the *units* measured on the weight. The rest of the data treatment is really about manipulating equations.

For the case of those concepts of evidence associated with evaluation, the students might be encouraged to discuss *uncertainties and errors*, especially if their results are far from the table value. The same thing occurs for the *reliability*. *Validity* is brought up since the students are encouraged to discuss the rationale behind an indirect measurement.

Specific evaporating heat of water

The purpose of the labwork - as described in the labguide - is to determine the specific evaporation heat of water. See figure E.9 for a copy of the labguide.

The labwork is done by placing an amount of water in an electric kettle at bringing it to boil. The total mass of the kettle and the water is determined. While monitoring the energy consumption, the water in the electric kettle is to be boiling for approximately 100 seconds without the lit on, and the total mass is again determined. In this way the energy used to evaporate the amount of water equal to the mass loss is measured, and from that the specific evaporating heat of water can be determined. The students are asked to repeat the experiment.

In the labguide the specific evaporation heat is defined as

$$L = \frac{\Delta E}{\Delta m} \tag{E.3}$$

The students are asked to make their own measurement scheme, and to display their calculations of the specific evaporation heat. The students are asked to compare their two found results and the table value, along with commenting the measuring method and the sources of errors, especially in relation to discussing whether the sources of error causes a value of L to be too large or too small.

For those associated with design, *variable identification* is only touched upon, since the students might not need to identify the energy consumption as the independent variable and the mass loss as the dependent variable, since all they need is to calculate the derived variable of the specific evaporate heat. *Fair test*, *sample size* and *variable type* are not relevant.

For the case of those skills associated with measurement, *relative scale* will only be brought up if the kettle runs dry. *Range and intervals* and *choice of instrument* are not relevant. *Repeatability* is addressed, since the students are asked to repeat the experiment and hopefully compare the results. *Accuracy* is not addressed, whereas *uncertainties* are touched upon when discussing the sources of error and which direction they will draw the result.

For the case of data handling, the students need to design their own table, and therefore *tables* come in play. They also might need to address *units*, but the rest is not dealt with for this labwork.

For those associated with evaluation, *uncertainties and errors* are directly addressed, since the students are asked to evaluate the sources of errors and especially discussing which direction the sources of error pull the derived evaporating heat. Also the *reliability* is to some extent addressed in the labwork through the repeat of the experiment and the comparison with the table value.

Often this type of labwork is combined with the measure of efficiency for an electric kettle.

Figure E.9 Labguide for specific evaporating heat of water, page 1 of 1.

Vands specifikke fordampningsvarme bestemt med elkedel

Du skal her finde vands specifikke fordampningsvarme, $L = \frac{\Delta E}{\Delta m}$

Ideen i forsøget

Vi anbringer en elkedel med noget vand i på en vægt. Vi vil lade vandet koge i nogen tid og finde sammenhængen mellem fordampet vandmængde og tilført energi, som vi vil måle med et energimeter.

Fremgangsmåde

- Fyld ca. ½ L vand i kedlen. sæt låg på, tilslut til elnettet og bring vandet i kog.
- Sluk for strømmen og sæt *hurtigt* elkedlen på en vægt — uden netledning i kedlen og uden låg — og find den samlede masse $m_{\text{før}}$.
- Tag *hurtigt* kedlen ned fra vægten og tilslut netledningen gennem energimåleren. Lad kedlens låg stå åbent under resten af forsøget og lad vandet koge i ca. 100 sekunder - uden låg på kedlen.
- Sluk for strømmen, aflæs energiomsætningen under kogningen og foretag en ny vejning — igen uden isat netledning — m_{efter}, så du kan beregne, hvor meget vand, der er fordampet.
- Gentag forsøget!

Databehandling

Lav et passende skema til dine måledata og vis beregningen af L. Sammenlign resultaterne i dine to bestemmelser af L og sammenlign med tabelværdien.

Kommentér målemetoden — er der fejlkilder? Betyder eventuelle fejlkilder, at du måler dig frem til en for stor eller en for lille værdi for L?

Efficiency of e.g. coffee maker

The purpose of the labwork - as described in the labguide - is to determine the efficiency of a coffee maker with small and large amounts of water and to determine the price of the electricity used to make a pot of coffee. A copy of the labguide can be found at figure E.10.

The labwork is done by measuring the electric energy used to heat the water. The mass of the water and its initial and final temperature are measured, and on that ground the efficiency can be determined.

The students are asked in the labguide to note down the electric energy consumption in kWh and Joule, and on the basis of the mass of the water, the temperature difference and the specific heat capacity of water the needed energy to heat the water is determined. On that basis the efficiency is determined. The labwork is to be repeated with different water amounts. The measured efficiencies are to be compared, and the reasons behind a difference is to be discussed.

This labwork addresses a number of the sub-categories of the procedural skills. For those associated with design, again the *variable identification* is relevant, but not addressed or needed to pursue the task. The rest of the sub-skills associated with design are not addressed.

For those associated with measurement, none of the sub-skills are relevant.

For the sub-skills associated with data handling, the *units* come into place when discussing kWh and Joule. Hopefully also *patterns* will be discussed when determining the energy loss and the efficiency values.

For the labwork, the *uncertainties and errors* are discussed, since the labwork is repeated with different water amounts to investigate its effect on the efficiency.

Optical grating/distance of furrow of cd

According to the labguide this labwork has a twofold aim: (1) to determine the separation of the slits in an optical grating, and (2) to determine the distance of the furrows of a compact disc. A copy can be found in figure E.11-E.13.

The twofold aim indicates two experiments, each using a He-Ne laser with a known wavelength. For the first experiment an optical grating is placed in the laser beam and the distance between the incident and diffracted beams are measured on a distant wall, thereby being able to determine the diffraction angles and from the grating equation the slit separation. The second experiment is done by placing the reflecting side of a compact disc in the incident laser beam and measuring the diffraction points on the wall behind the laser. Again by use of the grating equation, the students should be able to determine the slit separation (equal to the distance of furrows) on a compact disc. It is in

Figure E.10 Labguide for efficiency of e.g. coffee maker, page 1 of 1.

Nyttevirkning for en kaffemaskine

Tegn opstillingen:

En kaffemaskine forbindes via en el-måler til en 220 V stikkontakt. Hæld ca. 1 liter vand op i et glasbæger. og bestem vandmassen mv ved vejning. Begyndelsestemperaturen T_1 aflæses.

Når maskinen har opvarmet vandet, afbrydes strømmen. Sluttemperaturen T_2 måles. El-måleren aflæses ved at tælle antallet af omdrejninger i den tid, kaffemaskinen var tændt. 2400 omdrejninger = 1 kWh.

1 omdrejning svarer til: ____________ kWh

Antal omdrejninger = ____________

$E_{tilført}$ = ____________ kWh. Omregn $E_{tilført}$ til ____________ joule. 1 kWh = $3.6 \cdot 10^6$ J

$E_{tilført}$ = ____________ joule

Vandets masse = m_v = ____________

Vandets varmefylde= c_v = 4,18 J/(g·grad)

Starttemperatur = T_1 = ____________

Sluttemperatur =T_2 = ____________

Nyttevirkning = $E_{udnyttet}/E_{tilført} \cdot 100\%$ = ____________

Forsøget gentages med f.eks.:

- Meget/lidt vand

Hvad er el-prisen for en kande kaffe?

(1 kWh koster 86 øre)

Er nyttevirkningen ens i alle forsøg?

Hvad kan årsagen være til afvigelsen?

Figure E.11 Labguide for optical grating/distance of furrow of cd, page 1 of 3.

Anvendelse af laseren til bestemmelse af små afstande

Formålet med øvelsen er

1. at bestemme gitterkonstanten d for et optisk gitter (transmissionsgitter)
2. at bestemme rilleafstanden på en CD.

Apparatur:
He-Ne laser (λ = 632,8 nm), optisk gitter (d = 1/100 mm), CD, timerstrimmel, lineal.

Teori:
1. Optisk gitter
Når lys med bølgelængden passerer et optisk gitter med gitterkonstanten d, vil der efter gitteret observeres konstruktiv interferens af lyset i de retninger, der er givet ved gitterligningen:

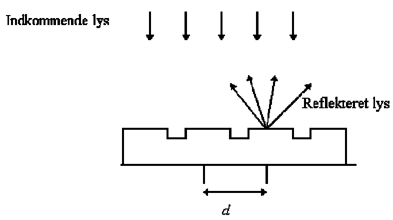
$$d \cdot \sin\theta_n = n \cdot \lambda$$

2. Rilleafstand på CD
Overfladen af en almindelig CD indeholder et stort antal tætliggende riller. Overfladen mellem rillerne fungerer som spejl, når den belyses; se figur 1.
Som det er antydet på figuren, vil hver enkelt af CD-overfladens reflekterende dele fungere som udgangspunkt for en ringbølge på samme måde som spalterne i et optisk gitter. Det reflekterede lys fra overfladen vil derfor interferere konstruktivt efter samme betingelser, som er gældende ved det optiske gitter, altså i retninger som er givet ved:

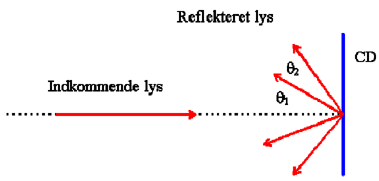
$$d \cdot \sin\theta_n = n \cdot \lambda$$

hvor d nu repræsenterer afstanden mellem rillerne i CD-en som vist på figur 1; sml. figur 2.

Figur 1:



Figur 2:



Udførelse:
Under udførelsen af målingerne skal man hele tiden være opmærksom på, at laserlyset kan være skadeligt for synet. Man skal undgå at få det direkte eller reflekterede laserlys i øjnene, og laseren må ikke flyttes, når den er tændt.

Optisk gitter:
Laseren stilles på bordet, således at strålen falder vinkelret ind på den modsatte væg. Gitteret placeres vinkelret på strålen, og man kan nu iagttage interferenspletterne på væggen. Et stykke timerstrimmel fæstnes på væggen, således at mindst 8-10 interferenspletter falder inden for strimmelen. Positionen af hver plet markeres tydeligt på strimmelen. Afbøjningsordenen noteres, f.eks. ved at man tydeligt markerer den plet, som svarer til den direkte stråle (0-te ordens afbøjning). Den vinkelrette afstand l fra gitteret til væggen måles og noteres. Der laves en strimmel til hver deltager på holdet.

Figure E.12 Labguide for optical grating/distance of furrow of cd, page 2 of 3.

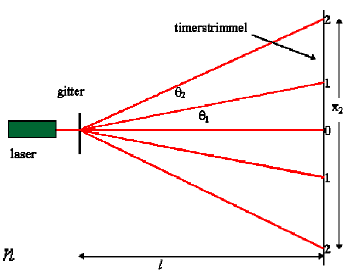
Rilleafstand på CD:
Laseren stilles op vinkelret på bagvæggen. CD-en fastspændes i et stativ og opstilles i laserstrålen, således at den belyses vinkelret på sin flade. Strålen skal ramme CD-en nær kanten, hvor krumningen af rillerne er mindst, og i samme højde som CD-ens centrum. CD-en rammes rigtigt, når det lys, som spejles direkte tilbage, reflekteres ind i laseren.
På bagvæggen kan man nu se interferenspletterne. Afstanden x_1 mellem de to førsteordens pletter måles og noteres. Hvis det er muligt måles tilsvarende afstanden x_2 mellem de to andenordens pletter. Desuden måles afstanden l fra bagvæggen til CD-en.

Databehandling:
1. Optisk gitter
Forsøgsopstillingen fremgår af figur 3. For hver afbøjningsorden måles afstanden xn mellem de to interferenspletter. Herefter kan sin(vn) findes ved hjælp af formlen:

$$\sin(\theta_n) = \frac{x_n/2}{\sqrt{l^2 + (x_n/2)^2}}$$

(1)

Figur 3:



Omskrivningen:

$$d \cdot \sin(\theta_n) = n \cdot \lambda \quad \Leftrightarrow \quad \sin(\theta_n) = \frac{n \cdot \lambda}{d} = \left(\frac{\lambda}{d}\right) \cdot n$$

viser nu, at hvis man afbilder sin(v) som funktion af n på et stykke almindeligt millimeterpapir, skal målepunkterne ligge på en ret linie gennem (0,0). Grafen tegnes, kommenteres og benyttes til bestemmelse af gitterkonstanten *d*. Den fundne værdi for *d* sammenlignes med den værdi, som er angivet på gitteret.
I rapporten skal desuden indgå en begrundelse for formel (1).

2. Rilleafstand på CD
Overvej selv, hvordan man finder sin(ϖ_1) og dernæst rilleafstanden *d* på grundlag af de udførte målinger. Udregningen gentages for anden afbøjningsorden, hvis den er målt.

Figur 4

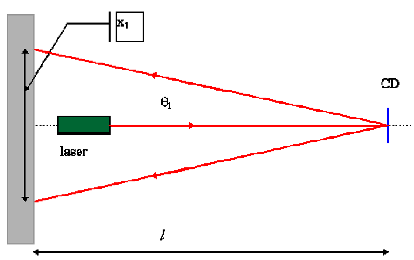


Figure E.13 Labguide for optical grating/distance of furrow of cd, page 3 of 3.

Måleresultater:
1. Optisk gitter

Afstand fra gitter til timerstrimmel *l* / m : =			
N	x_n / m	½·x_n / m	sin(ϖ$_n$)
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

2. Rilleafstand på CD

Afstand fra CD-en til bagvæggen l / m =				
n	x_n /m	½·x_n / m	sin(ϖ$_n$)	*d* / m
1				
2				
3				

the labguide explained that the experiment should be done for the outer part of the compact disc to make sure the furrows are as plane as possible. Also explanations are given as to how to make sure the compact disk is perpendicular to the laser beam.

For the first experiment, the data treatment is done by calculating sinus to the diffraction angle (though geometrical considerations), and then plotting it against the diffraction number. This should according to the grating equation

$$d \cdot \sin\theta_n = n \cdot \lambda$$

give rise to a proportionality with the slope of λ/d, where λ is the known wavelength of the laser light, n is the diffraction number, $\sin\theta_n$ is the diffraction angle for the n'th diffraction and d is the sought for slit separation. The graph is to be commented on and used to determine d. The found value of d is to be compared with the on the grating subscribed value.

For the second experiment, the same thing is done, but now the students need to determine how to geometrically calculate the diffraction angle and the furrow distance based on the done measurements.

For this labwork, a number of sub-skills are addressed. For those associated with design, the *variable identification* is poorly addressed, since the students will not gain a feel of being able to alter an independent variable and then measure the dependent variable - everything is settled by the choice of the laser. What could be addressed though are the *variable types*, since for this labwork the diffraction numbers are discrete, but this does not give rise to a discussion in relation to the *graph types*, since the students are asked to do a 'normal' line graph. The *fair test* and *sample size* are not addressed.

For those associated with measurements, the *relative scale* could be addressed when choosing the distance between the grating or compact disc, and the walls where the diffractions are displayed. But it is not asked to be discussed. The rest of the sub-skills are not addressed.

For those associated with data handling, the *tables* are already displayed in the labguide. As discussed before, the *graph type* skills could be discussed, but are 'taken care of' in the labguide. But on the other hand, this labwork is used to interpret and extract information and discuss the data displayed in a graph, thereby indicating graph understanding skills, but this might relate more to the *patterns* skills - since *patterns* are to be detected, especially for the first experiment, where more diffraction points are expected to emerge. The rest of the skills associated with data handling are not addressed.

For those associated with the evaluation, *uncertainties and errors* are somewhat addressed when comparing the measured slit separation and comparing it to the printed value. In the same way, *reliability* and *validity* are not directly addressed.

Additional for this labwork, some geometric (mathematics) are needed to answer the questions related to the data handling. So generally, this labwork primarily shows the applicability of the taught mathematics.

Standing waves in tube / speed of sound

According to the labguide the aim of the labwork is to investigate (sound) waves in a resonance tube and to determine the speed of sound in atmospheric air. A copy of the labguide can be found at figure E.14-E.15.

The labwork is done by placing water in a tube, where the water level is adjustable. A frequency generator is attached to a loudspeaker placed above the tube. A frequency counter is also attached to the frequency generator for a more precise read-out of the frequency. The frequency generator is turned on with a frequency of approximately 800 Hz. The water level is then reduced until the sound is strongly enhanced (resonance), and the position of the water level is noted. The water level is again reduced until the next resonance position is found. This is repeated until the water level is at its lowest. Finally, the room temperature is noted down. The experiment is repeated with a frequency around 1500 Hz and 2000 Hz.

On the basis of the measurements of the water level positions l_n for the various resonances n, l_n can be plotted against n and on the basis of the resonance equation

$$l_n + d = \frac{\lambda}{4} + n \cdot \frac{\lambda}{2}$$

the wavelength λ velocity can be deduced from the slope of the (n, l_n) graph. Since the frequency of the sound is known, the velocity of sound can be determined. This is done on the data for all three frequencies, and the found velocities are to be compared with a table value of the speed of sound for the specific room temperature through

$$v = 331m/s \cdot \sqrt{\frac{T}{273K}}$$

where T is the absolute room temperature.

For the skills associated with design, the students might need to consider issues of dependent and independent variables, since they change the water level looking for the resonance notes, leading on to questions of what is the dependent and independent variable. This is also a case for the *variable types*, since the resonance notes are a discrete variable. *Fair test* and *sample size* is not relevant.

For those associated with measurements, the *relative scale*, *range and intervals* and *choice of instrument* are taken care of by the apparatus. Question of *repeatability* might come up when trying to find the best resonance water level,

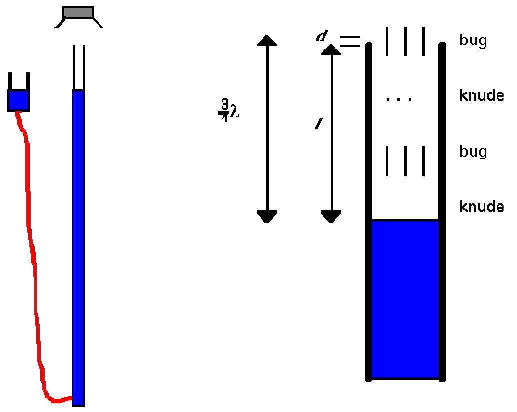
Figure E.14 Labguide for standing waves in tube / speed of sound, page 2 of 2.

Øvelsens formål

Formålet er at undersøge stående bølger i et resonansrør, samt at bestemme lydens fart i atmosfærisk luft.

Forsøgsopstilling

Opstillingen fremgår af figurerne herunder. Desuden bruges en tonegenerator og en frekvenstæller.



figur 1 Forsøgsopstilling figur 2 Den anden resonans i røret

Øvelsens udførelse

Højttaleren anbringes vha. et stativ over resonansrørets munding, således at lyden fra denne sendes ned i røret. Højttaleren forbindes til tonegeneratoren. Frekvenstælleren forbindes også til tonegeneratoren.

Tonegeneratoren indstilles til en frekvens på ca. 800 Hz. Den præcise frekvens aflæses på *frekvenstælleren* og noteres.

Niveaubeholderen, der er fyldt med vand, forskydes opad, således at resonansrøret fyldes med vand - indtil vandet står nogle få cm fra rørets kant.

Nu sænkes niveaubeholderen, indtil vandstanden i røret er sådan, at der høres en kraftig forstærkning af lyden - også kaldet resonans. Afstanden fra rørets kant til vandoverfladen noteres (nøjagtighed 0.1 cm). Dernæst sænkes vandstanden, indtil næste resonans høres. Igen noteres afstanden fra rørets kant til vandoverfladen - osv. Således fortsættes indtil niveaubeholderen ikke kan sænkes yderligere. Endelig noteres temperaturen i lokalet.

Figure E.15 Labguide for standing waves in tube / speed of sound, page 2 of 2.

Forsøget gentages med frekvenserne ca. 1500 Hz og ca. 2000 Hz. Husk igen, at den præcise frekvens aflæses på frekvenstælleren.

Du skal altid have lavet et måleskema i forvejen. Denne gang skal du have udfyldt det. Altså beregn alle resonanser for et rør der er 1.5 m langt. Det vil gøre det meget lettere for dig at lave forsøget! Når du laver forsøget, bør du være opmærksom på, at der skal være lige langt mellem knuderne.

Rapporten skal indeholde:

Under afsnittet teori skal du bl.a. gøre følgende: tegn 3 figurer, som viser beliggenhed af svingningsbuge og svingningsknuder for de tre første resonanser i røret (ved samme frekvens), således at de tre figurer har det rigtige indbyrdes størrelsesforhold! se om nødvendigt den første af figurerne på side 1 i vejledningen.

Den første resonans i røret tildeles nummeret 0, den næste 1 osv. Kaldes rørets længde for *l* og resonansnummeret for n, gælder følgende formel:

$$l + d = \frac{1}{4}\lambda + n\frac{\lambda}{2}, \quad n = 0, 1, 2, \ldots$$

hvor *d* er det stykke, som svingningsbugen ligger uden for rørets munding (se fig. 2).

Formlen for rørlængden *l* udtrykt ved bølgelængden λ (og *d*) skrives på ved hver figur.

Besvar desuden spørgsmålet: hvad er afstanden mellem to på hinanden følgende resonansrørlængder - udtrykt vha. bølgelængden?

Desuden skal du anføre formlen for lydens fart - udtrykt vha. bølgelængden og frekvensen.

Udregn »tabelværdien« for lydens fart vha. følgende formel:

$$v = 331\frac{m}{s} \bullet \sqrt{\frac{T}{273\,K}}$$

hvor *T* er den absolutte temperatur i lokalet.

Ved behandlingen af måleresultaterne skal du afbilde resonansrørlængderne som funktion af deres nummer (husk, at det første er 0). Alle 3 forsøg indtegnes i samme koordinatsystem. Dernæst bestemmes hældningskoefficienterne - og udfra disse findes bølgelængderne.

Endelig beregnes lydens fart i hvert af de 3 forsøg. Disse værdier sammenlignes med lydens fart beregnet udfra temperaturen i lokalet.

Benyt et edb-program til graftegning og regn liniernes hældning ud vha lineær regression.

and *accuracy* might be addressed when determining the resonance point and measuring its position. *Uncertainties* are not addressed.

For those associated with data handling, the students are asked to calculate theoretical positions before the experiment, leading on to enhance the role of the table and developing *tables* skills. Also the graph type could be discussed, especially since the resonance notes are discrete. This is though dictated by the labwork, and therefore most likely will not be taken up. *Patterns* and the discussion of the data as displayed in the graph are definitely a part of the labwork. *Multivariate data* might come up when discussing how to include all three data series in one graph, but it is not directly discussed. *Units* are addressed, since the table value comes in the unit of meter pr. second, and most likely the result from the graph will come in centimetres pr. second. *Equation translation* will also be a part of this, since the students need to juggle between the line fit of the form $y = ax + b$ and the physical equations.

For those associated with evaluation, the *uncertainties* issues might come up when comparing the found speed of velocity with the table value. For the case of *reliability* and especially *validity*, it will most likely be though of as a quite complex way of measuring the somehow simple idea of speed of sound, which they e.g. know from lightning and thunder.

E.3.3 Specific labwork activities and their specific purposes (B-level)

Here the ten labwork activities determined for the B-level are described and then analyzed in relation to the sub-categories of the procedural skills domain.

Halftime

The labwork concerning the halftime for Barium-137 has according to the lab-guide (see figure E.16-E.17) the aim of measuring the halftime for a short-living isotope.

The labwork is done by filtering out the short-living Barium-137 isotopes created in a β-decay from a long-living Cs-137 solution. The radioactive decays of the Barium liquid are measured by a Geiger counter, with a count period of 30 seconds. The decay counts are detected and noted 20 times (until 600 seconds are passed).

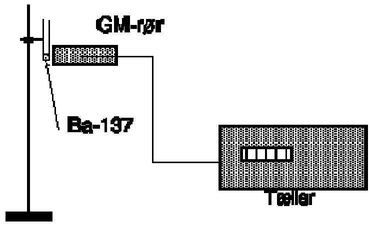
On the basis of the counts N and the count period, the activity is calculated ($A = N/30s$). The activity is plotted on a single-logarithmic paper as a function of time. Also the statistical uncertainty $\Delta A = \sqrt{N}/\Delta t$ is calculated and plotted on the graph. The best straight line between the measured points is drawn, and it is checked if it lies within the drawn uncertainties. Also the two lines within the statistical uncertainties give the steepest and shallowest slope are drawn. On the basis of the three lines, the most probable halftime, the largest possible halftime and the lowest possible halftime is determined and compared to a table

Figure E.16 Labguide for halftime, page 1 of 2.

Halveringstid for Ba-137

Formål:

At måle halveringstiden for en isotop med kort halveringstid.



Forsøgsbeskrivelse:

En "minigenerator" indeholder det radioaktive stof Cs-137, der har en halveringstid på 30 år. Ved en ß--proces henfalder Cs-137 til den kortlivede isotop Ba-137. Ved at gennemskylle "minigeneratoren" med en svag syreopløsning kan Ba-137 udvaskes fra kilden.

NB. Hvis I har lavet en udvaskning fra kilden, skal I vente ca. 15 min., før der er henfaldet nok Cs til en ny udvaskning af Ba-137.

Til forsøget gennemskylles minigeneratoren med ca. 1 ml. elueringsvæske. Tælleren stilles til at måle i 30 s. perioder Forsøget startes ved at trykke på reset knappen.

- t = tidspunktet i sekunder.
- N = tælletallet i tiden $\Delta t = 30$ s.
- $A = N \cdot 1/30$ = tællehastigheden.

t /s	30	60	90	120	150	180	210	240	270	300
N										
A										
√N										
$\Delta A = (\sqrt{N})/\Delta t$										

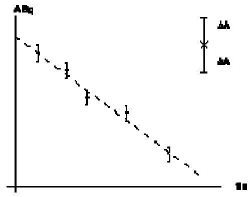
t /s	330	360	390	420	450	480	510	540	570	600
N										
A										
√N										
$\Delta A = (\sqrt{N})/\Delta t$										

Figure E.17 Labguide for halftime, page 2 of 2.

Databehandling:

Der foretages grafisk afbildning på enkeltlogaritmisk papir.

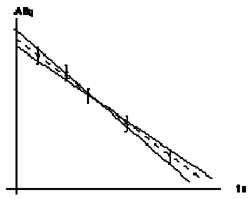
Den statistiske usikkerhed på et tælletal er $\sqrt{N}$. Følgelig bliver usikkerheden på aktiviteten $\Delta A = \sqrt{N}/\Delta t$.



Usikkerhedsfanerne indtegnes på en række udvalgte målepunkter, som vist på figuren til højre.

Det undersøges, om målepunkterne ligger på en ret linie inden for måleusikkerheden. På graferne aflæses halveringstiden $T_{1/2}$. Henfaldskonstanten k beregnes ud fra kendskabet til $T_{1/2}$.

$$A = A_0 \cdot e^{-kt} \quad ; \quad k = \frac{\ln 2}{T_{1/2}}$$



Resultat	k /s-1	$T_{1/2}$ /s
Ba-127		

På grafen indtegnes de to linier, som inden for måleusikkerheden giver den største og den mindste værdi for $T_{1/2}$.

Maximalværdi: $T_{1/2}$ = __________s

Minimalværdi: $T_{1/2}$ = __________s

Tabelværdi: $T_{1/2}$ = 156 s

value. No notion is taken of measuring points lying far from the linear regression. Also no notion on the background radiation is given.

For this labwork, time is the independent variable, which somehow serves another role than an independent variable which the students can directly alter (e.g. by turning a knob). This part of *variable identification* be addressed for the labwork. For the *fair test* and *sample size*, these could be addressed, but are in the labwork not. For the case of *variable types*, this labwork is interesting, since the measured dependent variable is a count of events happening within a time period, meaning it is discrete and of a different nature than a 'normal' continuous measurement of e.g. the weight as a function of height. These issues are though not addressed in the labguide.

For those sub-skills associated with measurement *relative scale* could be important, if the distance between the Geiger-tube and the substrate were too large, so the count number would be very small. No notion of the distance is given in the labguide, and some might therefore touch upon it. The *range and intervals* are taken care of by the labguide dictating measurements every 30 seconds for a period of 600 seconds. As this labwork indicate issues of statistical uncertainties, these ideas could be taken up in relation to the *choice of instrument*, but are not addressed in the labguide. Since the data are not repeated *repeatability* is not addressed. For the case of *accuracy*, the accuracy discussions are taken care of by the dictated choice of instrument, and are therefore not addressed. Finally for the case of *uncertainties*, this labwork deals with random uncertainties in discussing statistical precautions.

Tables are not really addressed, since this labguide includes a drawn table with room for all relevant measures. As discussed under *variable types*, there are in this labwork room for discussing discrete variables and interval measures also relevant for the *graph type*, but this is not taken up, and instead the students are described what to do. On the other hand, the students are addressing other *graph type* issues, such as single-logarithm, error bars and their affect on the uncertainty of the measured outcome. *Patterns* are surely addressed in this labwork, since the students are given the opportunity to discuss the formed pattern of the measures. *Multivariate data* are not addressed here. *Units* will most likely not be discussed, since everything is measured in seconds. Finally, *equation translation* are surely addressed, since the students need to compare their linear fit in a semi-logarithmic plot to an exponential function depending on the decay constant k in order to extract the halftime $T_{1/2}$.

Finally for those associated with evaluation, *uncertainties and errors* are addressed to a higher extend then any of the previous labwork activities. This does not necessarily lead on to a *reliability* discussion, and most likely not to *validity*.

Halfwidth

For the labwork concerning the halfwidth experiment, the extracted labguide concerns four labwork activities: (1) a measurement of the characteristics of the GM-tube, (2) a measurement of the background radiation, (3) the absorption of gamma radiation in lead, and (4) a measurement of the halftime of Barium-137. Since the halftime experiment already has been covered in the previous section, only the first three experiments are looked upon here. The labguide can be found at figure E.18-E.19.

For the first experiment concerning characteristics of the GM-tube, the connection between the potential U of the tube and the count speed I is investigated. I is plotted as a function of U, to determine the interval of U-values giving the highest count speed. The U-values are then chosen to lie in the middle of this interval for the rest of the experiments. Second experiment, concerning the background radiation, repeats a background radiation measurement in 30 second intervals ten times, and a mean is measured. For the third experiment concerning absorption of gamma-radiation in lead, the distance between the gamma source and the GM-tube is dictated to be approximately 10 centimetres. Three intensity measurements are done for each lead plate, and the mean is calculated.

For data handling, the background radiation is subtracted, and a graph on single-logarithmic paper is drawn showing the measured intensity as a function of the plate width x. The students are asked what could be concluded on the background of the graph. The students are also provided with the equation $x_{1/2} = \ln 2/\mu$, where μ is named the absorption coefficient and holding a unit of mm^{-1}. The students are asked to determine the halfwidth $x_{1/2}$.

This labwork serve a number of sub-skills related to the procedural skills domain.

For the two latter experiments, related to those associated with design, the students are in need of *identifying variables*: the dependent variable as the count number, and how this is a representative and proportional factor to the intensity, which is really the important factor. For the independent variable, it might be difficult to cope for the background radiation, but for the halfwidth experiment, it should be detected as the width of the lead plates. *Fair test* could be touched upon in discussing the distance between the source and the tube, and also in relation to keeping additional sources at a long distance, both for the background and the halfwidth experiment. *Variable types* could be addressed, since the students might take up discussions of the derived variable of the count number and its relation to the intensity. Also the students could encounter the fact that the count number is discrete and that it is a measure based on a time interval of 30 seconds.

For those associated with measurement, the *relative scale* is not touched

Figure E.18 Labguide for halfwidth, page 1 of 2.

Radioaktivitet

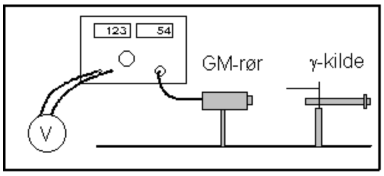
I denne øvelse bruges et GM-rør til at detektere gammastråling. Øvelsen omfatter flere forskellige punkter:

1. Måling af GM-rørets karakteristik
2. Måling af baggrundsstrålingen
3. Absorption af gammastråling i bly
4. Halveringstid af $^{137}Ba^{*}$

GM-røret kan sluttes til en tæller med dobbelt display, og resultaterne nedskrives efterhånden som de foreligger. Som alternativ kan benyttes dataopsamlingsudstyr (ADACT System, Ålborgkasse eller en tæller med seriel udgang) og et dertil beregnet dataopsamlingsprogram.
I hele forsøget registreres strålingen i 30-sekunders intervaller. Strålingens intensitet (tællehastigheden) I kan i rapporten angives som tællinger pr. 30 sekunder, eller omregnes til tællinger pr. sekund.

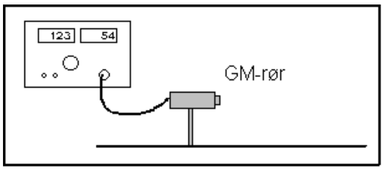
1) GM-rørets karakteristik.

Sammenhængen mellem rørets forsyningsspænding U og tællehastigheden I undersøges. Tegn en graf, som viser I som funktion af *U*. Bestem det interval af *U*-værdier, der giver den højeste tællehastighed, og vælg en *U*-værdi midt i dette interval til brug i resten af øvelsen.



2) Baggrundsstrålingen.

Alle radioaktive kilder skal være langt fra GM-røret. Baggrundsstrålingen registreres i et antal 30-sek. perioder, og der beregnes et middeltal. Der skal foretages mindst 10 målinger.



3) Absorption af γ-stråling i bly.

Afstanden fra GM-røret til gammekilden skal være ca 10 cm. For hver pladetykkelse foretages tre målinger af intensiteten, tag gennemsnit. Tallene korrigeres for baggrundsstrålingens indflydelse, og der tegnes en graf på enkeltlogaritmisk papir, som viser intensiteten som funktion af pladetykkelsen *x*. Hvad kan man konkludere fra grafen?
Grafens halveringskonstant, som kaldes halveringstykkelsen, bestemmes, og af formlen

$$x_{\frac{1}{2}} = \frac{\ln(2)}{\mu}$$

bestemmes absorptionskoefficienten μ i enheden mm^{-1}

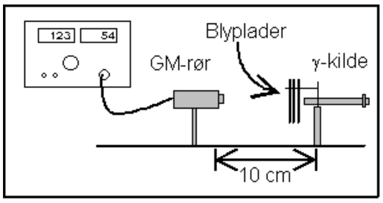
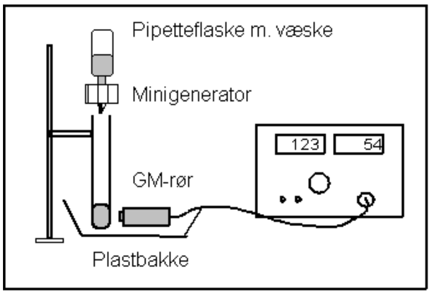


Figure E.19 Labguide for halfwidth, page 2 of 2.

4) Bestemmelse af halveringstiden for 137Ba*.



I forsøget måles på gammastråling fra radioaktiv 137Ba*. Det radioaktive Barium dannes som led i henfaldet af 137Cs , som i ca 93% af tilfældene omdannes til Barium med overskud af energi:

$$^{137}Cs \rightarrow {}^{137}Ba^{*} + \beta^{-} + \bar{\nu}$$

Denne proces er langsom, halveringstiden er ca 30 år. Det radioaktive Barium er derimod meget ustabilt, og omdannes til hurtigt til stabil Ba ved udsendelse af -stråling:

$$^{137}Ba^{*} \rightarrow {}^{137}Ba + \gamma$$

Det er denne gammastråling, vi måler på i forsøget.
Minigeneratoren indeholder ^{137}Cs, og dermed også Barium, som til stadighed dannes under omdannelsen af Cæsium. Pipetteflasken fyldes med ca 3 mL af en sur NaCl-opløsning. Opløsningen presses langsomt igennem minigeneratoren. Herved udvaskes noget af den ^{137}Ba, der til stadighed dannes i minigeneratoren, og drypper ned i reagensglasset. ^{137}Cs er derimod uopløselig. Minigeneratoren fjernes fra opstillingen, og tællingerne noteres, indtil tallene nærmer sig baggrundsstrålingen.
Hvis der er tid, gentages forsøget.
Intensiteten I korrigeres for baggrund, og tegnes som funktion af tiden i et enkeltlogaritmisk koordinatsystem. Hvad kan man konkludere af grafen? Kommenter grafens udseende!
Aflæs halveringstiden $T_{1/2}$, og beregn henfaldskonstanten k. Der gælder formlen

$$T_{1/2} = \frac{\ln(2)}{k}$$

k angives i enheden min^{-1} eller s^{-1}. Tabelværdien af $T_{1/2}$ er 2,6 minutter.

upon, but could be in relation to the position of source and its affect on the count numbers. For the *range and intervals*, the students probably address this while discussing how many plates to measure on, and whether it would be acceptable to add several plates at one time. The *choice of instrument* is touched upon in the first experiment, where knowledge of the GM-tube is gained. Also *repeatability* is added to this labwork since each measurement is to be repeated three times, which could lead on to discussions of varying values. *Accuracy* and *uncertainties* could be relevant for this labwork, but the labguide leaved this behind.

For those associated with data handling, *tables* and *graph types* serve a role in the labwork, but much more understanding could be gained in this labwork than the labguide leads on to. *Patterns* are for sure included, since the students are to plot the data and look for a linear pattern of the data in the semi-logarithmic plot. *Units* are not included, since it is taken care of by the labguide. *Equation translation* is a part of the labwork, since the students need to translate the fit equation to the physical equation.

Finally, for those associated with evaluation, *uncertainties and errors* are not discussed. *Reliability* could be included, but *validity* is not part of the task.

Spectral analysis

According to the labguide, see figure E.20-E.21, the labwork concerning spectral analysis are designed for the students to learn (1) to work with a goniometer, (2) to measure out the spectral lines in the Balmer series and based on this calculate the Rydberg constant, (3) to find the grating constant in a handed-out grating by working on a Sodium lamp, and (4) to identify the gas in a handed out spectral lamp by measuring the spectral lines of the lamp and compare it with information about wavelengths of light from various gasses, such as found in a data book.

The labwork contains three experiments. For the first experiment the students are to compare the first order observations from a Hydrogen lamp to the Balmer series.[1] The found data for the wavelengths of the first order purple, blue and red spectral lines are compared with the values of the data book, and the Rydberg constant is calculated and compared to a table value. Also it is investigated how many orders it is possible to see with the chosen grating (Rowland grating), which has a known grating constant.

[1] The Balmer series is a specific example of the Rydberg formula describing the light emitted/absorbed for all transitions of hydrogen

$$\frac{1}{\lambda} = R_H \left(\frac{1}{2^2} - \frac{1}{n^2} \right)$$

where λ is the wavelength, n is an integer larger or equal to 3, and R_H is the Rydberg constant. The Rydberg constant takes the value of $10,973,731.57m^{-1}$.

Figure E.20 Labguide for spectral analysis, page 1 of 2.

Spektrallinjer

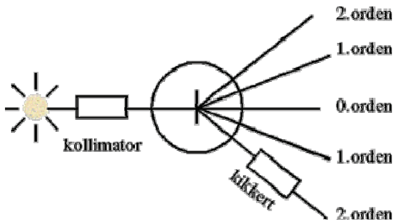
Formål

Du skal lære at

- arbejde med et goniometer
- udmåle spektrallinjerne i Balmerserien og ud fra dette udregne Rydbergkonstanten
- finde gitterkonstanten i et udleveret gitter ved at arbejde med en Na-lampe
- identificere gassen i en udleveret spektrallampe ved at udmåle spektrallinjerne for lampen og sammenligne med databogens oplysningen om bølgelængder i lyset fra forskellige gasser.

Apparatur

Du skal anvende et goniometer, to gitre og tre spektrallamper. Goniometeret består af et drejeligt bord, en kollimator, der samler lyset i en tynd stråle, samt en kikkert. På goniometerets bord kan man aflæse den vinkel, som kikkerten er drejet væk fra ligesigtende. Aflæsningen sker med en nonius, så aflæseusikkerheden bliver 0,1 grad.



Bemærk, at de udleverede spektrallamper skal tilsluttes specielle spændingskilder

Teori

Gør generelt kort rede for gitterligningen og for fremkomsten af spektrallinjer. Gør specielt rede for Balmerserien og herunder Rydbergkonstanten.

Udførelse og databehandling

For nøjagtighedens skyld aflæses afbøjningsvinklen til højre og afbøjningsvinklen til venstre. Ved beregningerne skal du anvende gennemsnittet af disse værdier

Figure E.21 Labguide for spectral analysis, page 2 of 2.

I de to første forsøg anvendes et Rowlandgitter. Husk at aflæse antal ridser pr. mm på gitteret. Udregn ud fra dette gitterkonstanten.

I første forsøg anvendes hydrogenlampen. Her skal du udmåle den violette, de to blå samt den røde spektrallinje af 1. orden. Indfør måleresultatet i et passende skema. Beregn bølgelængderne og sammenlign med databogens værdier. Beregn også Rydberg konstanten og sammenlign.

Undersøg medens hydrogenlampen er tændt, hvor mange ordener, du kan se med Rowlandgitteret.

I andet forsøg skal du stadig anvende Rowlandgitteret. Du skal udmåle de klareste linjer i spektret fra en lampe, der indeholder en luftart, som du skal identificere ved sammenligning mellem dine målte bølgelængder og databogens liste over bølgelængder fra forskellige stoffer.

I tredje forsøg skal du anvende natriumlampen sammen med et gitter, hvis gitterkonstant skal bestemmes. Lampen udsender i det synlige område kun lys med bølgelængden 589,3 nm. Aflæs for fx 8.orden afbøjningsvinklen til højre og til venstre. Beregn ud fra dette gitterkonstanten og dernæst antal ridser pr. mm for gitteret.

Skemakrav

Udtænk og anvend fornuftige skemaer til dine måledata og beregnede værdier. Skemaer giver et bedre overblik. Du skal i rapporten vise et eksempel på en beregning af hver type, du anvender.

For the second experiment the students are to recognize the brightest spectral lines from an unknown gas and identify the gas by use of the data book.

For the third experiment, the students are to use a Sodium lamp to calculate the grating constant by investigating high order spectral lines.

In relation to the sub-skills of the procedural skills domain, for those associated with design, the students are to be clear about the *variable identification*, since for the three experiments the variables somehow change roles. This understood as the angles of the various spectral lines in the goniometer are always what is to be measured, but which variable to be derived from this varies. This also strongly relates to the *variable types*, whereas *fair test* and *sample size* are not related to the labwork.

For those associated with measurement, the *relative scale* and the *range and intervals* are not related to the labwork. *Choice of instrument* serves some role, since the students need to investigate a possible difference between the measured angles to the left and right side. *Repeatability*, *accuracy* and *uncertainties* are not discussed in the labguide, but the *accuracy* might to some extent come up if the derived wavelengths, grating constant and Rydberg constant are far from the values of the data book.

For those associated with data handling, the students are themselves to design their *tables*, whereas the other sub-skills do not come into play.

Finally, for those associated with evaluation, *uncertainties and errors* are not related to the labwork, since no work in trying to extract the uncertainty of the goniometer measurements are done. *Reliability* is to be discussed in relation to the comparison with the data book values, whereas *validity* will most likely not be discussed.

Standing waves on string

According to the labguide (see figure E.22-E.23), the aim of the labwork is to study standing waves on a string and to verify that the wave velocity v is given by

$$v = \sqrt{\frac{F_S}{\rho_L}} \tag{E.4}$$

where F_S is the tension in the string and ρ_L is the mass pr. length of the string.

The labwork is done by placing a nylon string stretched out between a vibrator attached to a function generator and a pulley. The string is pulled over the pulley and a pull weight is attached to the end of the string. The distance between the vibrator and the pulley L is kept constant. By adjusting the frequency generator the fundamental tone and the first two overtones are found (equal to $\lambda = 2L$, $\lambda = L$ and $\lambda = 2/3L$), and the frequencies are noted down. The experiment is repeated with three different strings, and for each string

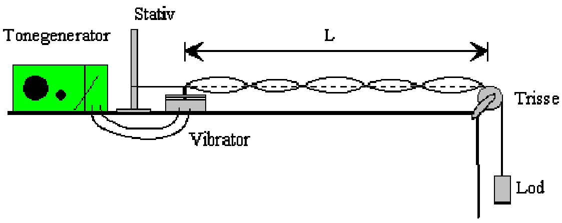
Figure E.22 Labguide for standing waves on string, page 1 of 2.

Stående snorbølger

Formålet med øvelsen er at studere stående bølger på en snor, og eftervise, at bølgernes udbredelseshastighed v er givet ved

$$v = \sqrt{\frac{F_S}{\rho_L}}$$

hvor ρ_L er snorens masse pr. længdeenhed, og F_S er snorspændingen. Følgende opstilling med en nylonline anvendes til forsøget:



Med tonegeneratoren sættes vibratoren i svingninger med frekvensen *f*. Frekvensen justeres, så der dannes stående bølger på tråden med bølgelængder $\lambda = 2\Lambda, \lambda = L$ og $\lambda = (2/3)\cdot L$, svarende til grundtonen og første og anden overtone. Snorens længde L skal være mellem 1 og 2 meter.

Forsøget udføres med tre forskellige liner, for hver line foretages målinger med tre forskellige værdier af FS (udskift loddet).

v bestemmes af $v = f\cdot\lambda$

F_S bestemmes af $F_S = m\cdot g$

r_L bestemmes af en længdemåling og en vejning.

Den teoretiske formel for hastigheden *v* kan eftervises på flere måder.

1. Beregn v af formlen, og sammenlign med de fundne middelværdier.
2. Af formlen følger, at

$$v^2 = \frac{F_S}{\rho_L}$$

For hver snor tegnes en graf, som viser v_2 som funktion af F_S. Begrund, at grafen burde blive en ret linje gennem (0,0), bestem hældningskoefficienten og undersøg, om dens værdi stemmer med det forventede.

Figure E.23 Labguide for standing waves on string, page 2 of 2.

SNORBØLGER	**1:ρ_L=______kg/m**			**2: ρ_L=______kg/m**			**3:ρ_L=______kg/m** >		
m /kg									
F_S /N									
f_0 /hz									
f_1 /hz									
f_2 /hz									
λ_1 /m									
λ_2 /m									
λ_3 /m									
v_0 /(m/s)									
v_1 /(m/s)									
v_2 /(m/s)									
<v> /(m/s)									
v_{ber} /(m/s)									
%-afvigelse									

(and each tone) three different masses of the pull weight are used. The mass pr. length of the strings are measured as well as the masses of the pull weights.

For the data treatment, two types of verifications are done, both assisted by a table for data and calculations. First the measured velocity is found by $v = f \cdot \lambda$, and the average of the three tones' velocities is found for the nine experiments (three string types times three pull weights). The measured mean velocities are compared to the theoretical value found by use of the equation for each of the three pull weights and three strings types, and the percent-wise deviation is found. Second a graph of v^2 as a function of F_S is plotted for each of the string types. The students are to explain why a linear graph through origo is expected theoretically. The slope is to be determined and compared to the theoretically expected value.

This labwork serve a number of sub-skills from the procedural skills domain. For those associated with design, *variable identification* is potentially a large hurdle, since the students both measure the mass of the pull weights, the weight pr. length of the three strings and the frequencies, and it might not be clear which role these serve in the data treatment. Thereby *fair test* and *variable types* are also dragged into this labwork, but by the dictated table for data and calculations and the data handling section of the labguide, this is more or less taken care of. *Sample size* is not relevant.

For those associated with measurement, *relative scale*, *range and intervals*, *choice of instrument* and *repeatability* are not relevant. *Accuracy* will most likely be touched upon in the comparing between the two ways of determining the velocity. *Uncertainties* could be investigated, especially if it proves that the found value of the velocity is always higher or lower than the theoretically predicted, though not addressed directly in the labguide.

For those associated with data handling, this labwork has more on its mind. Though the table is already made, *tables* are addressed in interpreting the table and over-viewing the many measurements. *Graph type* is addressed in understanding why it is relevant to plot the velocity squared, and why it is the plotted against the pull weight. *Patterns* are addressed in interpreting the graph, and so is *multivariate data*. *Units* might come into play when juggling between masses and lengths, and *equation translation* comes into play in relation to the fit of the graph and reversing it back to the equation.

For those associated with evaluation, *uncertainties and errors* as well as *reliability* could come into play. One could have hoped for more issues of the *validity*, since this comparison between a 'theoretical equation' (with measured inputs) and direct measurement of the velocity (which might not be interpreted as direct), could serve an interesting discussion.

Ideal gas

This labwork concerns Gay-Lussac's first law relating temperature and pressure. No labwork aim is stated in the labguide (see figure E.24).

The labwork is done by placing a digital temperature and pressure meter on a container (approximately half a litre). The temperature and pressure meter can be connected to a computer and read out by the software program 'Datalyse'. The container is placed in a kettle filled with ice-cold water. As the water is heated the temperature and the pressure in the container is measured approximately once every minute. When the water is boiling, the students are encouraged to let the water cool down and repeat the measurements, which also could serve as a test of the tightness of the connections between the container and the pressure meter.

The data treatment is done at the 'Datalyse' software, where four columns are made (time, pressure, temperature and a calculation of $P \cdot V/T$). The volume of the hose connecting the container to the digital meter is given in the labguide. When all measurements are done, the pressure is plotted against the temperature. The labguide is built in such a way that it seems most important to learn how to use the software 'Datalyse'.

This labwork deals with a number of the sub-skills related to the procedural domain. For those associated with design, *variable identification* are rather straight-forward, since the temperature is changed and the concurring pressure change is then measured. *Fair test* is somehow related to this, since some emphasis is put on the importance of keeping the container tight, but directly stating it is to make sure the amount of matter is kept constant is not done, and the idea of the matter particles and their movement in the container is not mentioned. *Sample size* is not relevant, as well as *variable types*.

For those associated with measurement, *relative scale* and *range and intervals* are taken care of by the labwork design. *Choice of instrument* could be taken up, especially since so much emphasis has been placed on teaching the students how to use the apparatus, but it is seen more as a manual than as an understanding. As for the same for *repeatability*, *accuracy* and *uncertainties*.

For those associated with data handling, the *tables* part has already been taken care of by the labguide. The *graph type* and *patterns* are somewhat relevant for the data treatment, but no further understanding is emphasized. *Multivariate data* and their effect are not taken up in this labguide, though it could have, e.g. for repeating with another volume or amount of matter. *Units* could be a significant issue if the gas constant was to be extracted from the data, but focus has been put on the proportionality. *Equation translation* is somewhat relevant, but again since the value of the slope is not emphasized, this is not truly taken up. This labwork could be quite relevant for finding a measure of

Figure E.24 Labguide for ideal gas, page 1 of 1.

Gay-Lussac's 1. lov

Apparatur:

- PTM100 temperatur- og trykmåler med serielt interface,
- en beholder på ca. ½ liter.
- og programmet Datalyse.

Forsøgsvejledning:

Beholderen tilsluttes trykindgangen på PMT100. Kom beholderen i en keddel med vand gerne iskoldt. Anbring termosonden tæt op ad beholderen. Den kan eventuelt bindes fast.

Det er meget vigtigt, at forbindelserne er tætte. Man kan eventuelt anskaffe et tilslutningsstykke fra Elcanic, så slangen fra PTM100 kan monteres på beholderen på samme måde som på PTM100.

Tilslut PTM100 til pc'en. Start programmet Datalyse og vælg apparat PTM100 og vælg multitabel.

Vælg en måling i minuttet og et passende antal punkter. Man kan altid afbryde dataopsamlingen, når vandet koger, eller man kan lade målingerne fortsætte under afkølingen. Herved kan man kontrollere om forbindelserne er tætte.

Udsnit af tabel fra Datalyse:

De 3 første søjler måles af Datalyse. I søjle 4 kan man eventuelt udregne P·V/T.

t/s	*P*/ kPa	*T*/K	

Når målingerne er færdige, afbildes trykket *P* som funktion af temperaturen *T*.
Slangens indre diameter er 3 mm og dens længde er ca 120 cm

the absolute zero temperature, but is not taken up here.

Most likely *uncertainties and errors* as well as *reliability* and *validity* will not be discussed.

Free fall (ball)

The labwork concerning the free fall of a ball (see figure E.25) aims at investigating the motion of a jumping ball, to determine the gravitational acceleration and to determine the loss of mechanical energy when the ball bounces against the floor.

The labwork is done by use of a distance measurer, measuring the distance to the nearest object within a 20 degree room angle by use of sonar. The distance measurer is tightened at approximately 2 meters above the floor. A ball is released approximately 0.4 meters below the distance measurer and set to measure every 0.3 second for 200 measurements by use of the software 'Datalyse' controlling the distance measurer. The ball is left to bounce against the floor and finally becoming steady. The measurements are repeated with different balls.

For the data treatment, obvious meaningless measurements are removed. The distance is reverted to the ball's height above ground, and the height is plotted against time. The patterns of the graph are discussed in relation to the physical situation. By use of a function in the software called 'differentiation' a calculated velocity as a function of time is plotted, and by use of linear regression the gravitational acceleration is derived. Finally for each bounce a part of the kinetic energy is lost, and the fractional loss is found by use of an included software function called 'maximum' the top point for each jump is found, and by comparing these top points the fractional kinetic energy loss can be derived.

A number of sub-skills in the procedural domain come into play for this labwork. For those associated with design, *variable identification*, *fair test*, *sample size* and *variable types* are all taken care of by the setup. Many considerations on this occur when the data needs to be handled, but design-wise the labguide takes care of the issues.

For those associated with measurements, *relative scale* and *range and intervals* are pre-determined by the labguide. *Choice of instrument* will to some extent come into play when understanding false measurements and why the data is reverted compared to the more intuitive motion. *Repeatability*, *accuracy* and *uncertainties* are not relevant for this labwork.

For those associated with data handling, the role of *tables* is special, since the software produces the tables, but the students afterwards have to manipulate them within the software in a number of probably unfamiliar ways (numeric differentiation, maximum value within intervals). This can give rise to a deeper understanding of applying operators to columns of data, but might also cause

Figure E.25 Labguide for free fall (ball), page 1 of 1.

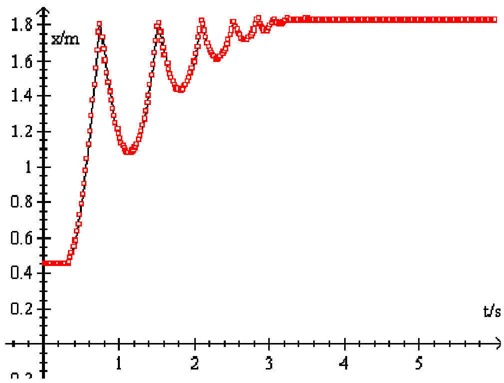
Den hoppende bold

Formål
Formålet med forsøget er at undersøge bevægelse af en hoppende bold, bestemme tyngdeaccelerationen og beregne det mekaniske energitab ved boldens stød med gulvet.

Apparatur
LabPro, motion detector, Datalyse og bolde.

Teori
Bolden er kun påvirket af tyngdekraften $F_t = m \cdot g$, hvor m er massen og g er tyngdeaccelerationen. Bolden falder derfor med konstant acceleration.

Forsøgsvejledning
Med en afstandsmåler kan man måle afstanden til et legeme. Sonden måler afstanden ved at udsende et lydsignal og måle tiden, fra signalet er afsendt, til signalet er reflekteret til sonden. Ved at udsende signaler fx hvert 0,03 sekund, kan man få løbende værdier af afstanden fra sonde til legeme. Sonden måler afstanden til nærmeste legeme inden for en rumvinkel på 20° og inden for afstande fra ca. 0,40 m til ca. 6 meter.
Sonden anbringes på ca. 2 meter over gulvet og bolden holdes ca. 40 cm under sonden. LabPro styres fra Datalyse. I Datalyse vælger man LabPro som apparat og vælger i menuen for apparatet »Måling (t, f(t))«. Her indstilles antal målinger fx til 200 og tid pr. måling til 0,03 sekund og som sonde vælges afstandsmåler. Sonden klikker, når den måler. I praksis kan målingen derfor foretages ved at en person sidder ved pc'en og styrer Datalyse, og en anden person holder bolden. Når sonden begynder at klikke, slippes bolden. Bolden bør blive liggende på gulvet under sonden.
Når sonden holder op med at klikke, kan målingerne analyseres. Slet meningsløse målinger. Grafen vil se ud som vist til højre.
Foretag forsøg med forskellige bolde.



Behandling
I forsøget måles afstanden fra sonden til bolden og ikke boldens højde over jorden. Boldens højde h udregnes som en søjleoperation i tabellen i Datalyse. Afstanden fra sonden til bolden kan bestemmes ved en måling, hvor bolden anbringes på gulvet. Afbild nu boldens højde over jorden som funktion af tiden. Diskuter den fysiske situation og forklar grafens udsendende. Vælg dernæst differentiation i Datalyse og bestem tyngdeaccelerationen vha. lineær regression for hvert hop.
Hver gang bolden rammer jorden, mister den en del af sin kinetiske energi. Beregn denne brøkdel for hvert hop, benyt funktionen maksimum i Datalyse til at udregne højderne.

so much confusion the students feel in need to slavishly follow the labguide. The students need to understand *graph types* when displaying the data, and a high level of understanding are needed to fully grasp the graphs and what they tell physically. This is related to *patterns*, and especially the display of the differentiated position might give rise to profound understanding, if the graph is fully grasped. *Multivariate data* has some relation to this labwork, since it is done for several different balls, but most likely the students will view them as different experiments and therefore not make the connection. *Units* will most likely not be considered, since it is the patters (and for the last task the fraction), which is important. *Equation translation* could be a major issue, but it depends on how the students gain to understand the graphs (formula-wise or phenomena-wise).

For those associated with evaluation, *uncertainties and errors* play a minor role. Also *reliability* and *validity* is not touched upon.

Friction (incline or drag)

This labwork considering motion with friction - see figure E.26 - aims according to the labguide of measuring the dynamic coefficient of friction for a block being dragged over a table and pulled up an incline.

The block is pulled by a string attached to a pull weight. The string is placed over a pulley. The pulley is attached to a software program enabling a measurement of the position as a function of time. The block and the pull weight are weighed, and a number of experiments are done where the pull weight drags the block along the table, varying the mass of the block and the pull weight. Second, the table is inclined such that the block is pulled upwards. The angle is measured. Experiments are done with different pull weights, block masses and incline angles.

The data handling is done by plotting the position as a function of time for each experiment. By doing numerical differentiation (a build-in feature of the software), also graphs of the velocity as a function of time is plotted. By doing linear regression on the velocity versus time graph, a value of the acceleration of the block can be found (it is constant, since no forces change on the block after it has started). By calculating the acceleration (or resulting force) on the block theoretically and comparing it to the measured value, the coefficient of friction can be extracted. This is to be done for each experiment, and the mean and spread of it is to be found.

Turning to the type of sub-skills which this labwork could serve, for those associated with design it seems obvious how the extended use of data collection software provides the students with clear-cut results for this part, and can therefore not be put as the potential learning outcome of the task.

The same thing occurs with the sub-skills associated with measurement. The

Figure E.26 Labguide for friction (incline or drag), page 1 of 1.

Bevægelse med gnidning

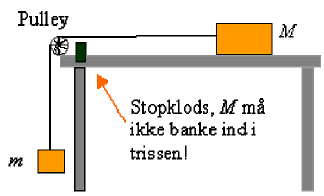
Øvelsens formål

Formålet er at bestemme den dynamiske gnidningskoefficient for en klods, der
1. trækkes hen over et bord.
2. trækkes op ad et skråplan.

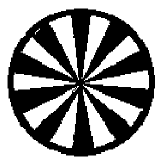
Apparatur

Til forsøget bruges en klods, et lod, en Smart Pulley Timer og programmet Datalyse. Smart Pulley Timer består af en lysvej og en trisse med 10 eger. Pulleyen er tilsluttet game-porten på en pc. Smart Pulley Timer vælges i Datalyse. Når egerne bryder lysstrålen, registrerer programmet tidspunktet. Efter endt måling tegnes en (*t*,*s*)-graf på skærmen. Hastigheden i bevægelsen fås ved differentiation, og accelerationen bestemmes vha lineær regression.

Forsøgsopstilling:



Trisse:



Forsøg 1: Trisse:
Først udføres forsøg, hvor et lod *m* trækker en klods *M*. Der laves ekstra forsøg med belastning af klodsen og af loddet. Bevægelsen startes ved at stramme snoren op og give slip på loddet. Gives der slip på klodsen, opstå der svingninger i snoren! Husk at veje *m* og *M*. Gem data efterhånden som forsøgene laves!
Forsøg 2:
Så klodses bordet op i den ene ende, så klodsen trækkes opad: Der laves igen forsøg med ekstra belastninger af *M* og eventuelt med forskellige vinkler af bordet. Husk at veje *m* og *M* og måle vinklen - find selv en metode.

Rapporten skal indeholde:
Eksempler på (*t*, *s*)-grafer og (*t*, *v*)-grafer. Opskriv udtryk for den resulterende kraft på systemet og udled vha Newtons 2. lov et udtryk for gnidningskoefficienten μ. Udregn μ. for alle forsøg. Find middelværdi og spredning på μ. Undlad dog afvigende målinger i disse beregninger. Husk at begrunde!

real work for this labwork enters with the data handling.

For those associated with data handling, the software provides the students with a table of time and position. Here the students need further to extract the velocity, and therefore *tables* come into play, though less profound than in the free fall labwork. The graphs displayed are not discussed in relation to the variable types, so the *graph types* are less profound, whereas the *patterns* are crucial for this labwork. As was also the case of the previous labwork, most likely *multivariate data* and *units* do not come into play, whereas *equation translation* is of significant importance for this labwork.

For those associated with evaluation, the students are asked to calculate the mean and spread of the friction coefficients. The uncertainties are not linked to the embedded uncertainties within the used apparatus, but are only viewed as a statistical uncertainty, giving rise to some understanding of *uncertainties and errors*, whereas *reliability* and *validity* most likely will not be addressed.

Air track (energy conservation, Newton's 2nd law)

In this labwork concerning Newton's second law measured on an air track, the aim is to verify the law for a two-body system affected by a constant resulting force. See figure E.27-E.29 for a copy of the labguide. This labwork bares close resemblance to the case teacher Burt's labwork concerning conservation of mechanical energy, though with a more refined data collecting device.

The labwork is done by placing a cart on an air track. The cart is pulled by a string over a pulley attached to a pull weight. The pulley can through a software program display the motion of the string (and thereby cart and pull weight) as a function of time. The cart is released on the air track and is pulled by the pull weight. The experiment is repeated for a number of different masses for the cart and the pull weight.

The data treatment is done by plotting the position versus time graphs to see if they are reasonable. If so, the position is numerically differentiated (included feature of the software), and the derived velocity is plotted against time. If the graph appears linear, then linearity of Newton's second law is verified. By linear regression the resulting acceleration is determined and compared to the theoretically predicted $a_{theory} = F_{res}/m_{res}$, and the percent-wise difference is calculated. Finally the students are asked to consider some issues in the report: (1) relating to sources of error which will reduce the measured acceleration? (2) evaluating the results does the velocity increase linearly as a function of time? (3) evaluating the results is the measured and theoretically predicted acceleration consistent? (4) if the measured and predicted acceleration are both given with e.g. four significant digits and only are consistent on the first two, how should this be interpreted?

Related to the sub-skills of the procedural domain, for those associated with design, again the labguide and the software take care of the issues related to the design.

For those associated with measurements, all but *uncertainties* are again taken care of by the software. *Uncertainties* are relevant, since the students later are asked to investigate which sources of error could lead to enhanced or reduced values of the acceleration compared to the theoretically predicted.

For those associated with data handling, the students are like in the previous two labwork activities asked to operate on the software-induced data table in order to collect the derivative of the position, giving them the opportunity to work with *tables*. The same thing goes with *graph types*. Again, as the previous two labwork activities, *patterns* play a significant role as well as *equation translation*, when the students need to compare data graphs to theoretical predictions. *Units* and *multivariate data* are not relevant.

For the case of evaluation, the last questions make sure the students spend time reflecting upon the method and the data, both related to *uncertainties and errors* as well as *reliability*. The *validity* is only hinted in the labguide.

Figure E.27 Labguide for air tract (energy conservation, Newton's 2nd law), page 1 of 3.

Newtons 2. lov med smartpulley

Øvelsens formål

At eftervise Newtons 2. lov i det tilfælde, hvor et system af to legemer påvirkes af en konstant resulterende kraft.

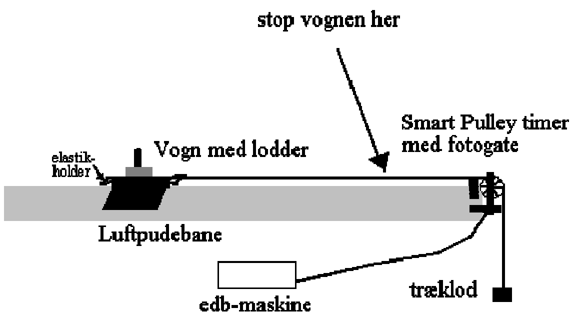
Teori

Ifølge Newtons 2. lov får et system en konstant acceleration, a = $\frac{F_{res}}{m_{res}}$, hvor m_{res} er masse af vogn + træklod. Newtons 2. lov forudsiger altså to ting:

- hastigheden vokser lineært som funktion af tiden, da accelerationen er konstant.
- accelerationen er givet ved ateori = $\frac{F_{res}}{m_{res}}$.

Øvelsen går nu ud på at undersøge, om påstand 1 og 2 er opfyldt. For at undersøge, om påstand 1 er opfyldt, afbildes de målte hastigheder som funktion af tiden. Hvis hastigheden afhænger lineært af tiden, er påstand 1 opfyldt. Påstand 2 er opfyldt, hvis den udfra grafen bestemte acceleration a_{eksp} stemmer overens med a_{teor} .

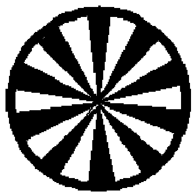
Forsøgsopstilling



På billedet herover ses opstillingen. Systemet bestående af vogn og træklod. Systemet accelereres af tyngdekraften på trækloddet. Vognen er forsynet elastikholdere i begge ender, således at hverken trisse eller vogn ødelægges, når vognen når enden af banen.

Figure E.28 Labguide for air tract (energy conservation, Newton's 2nd law), page 2 of 3.

Smart Pulley Trisse



Smart Pulley

Trissen er en Smart Pulley timer med fotogate. Trissen har 10 eger. Hver gang en nye ege bryder lyset, er vognen kørt 1,50 cm og samtidig har programmet Datalyse på pc'en aflæst tiden. Hænger loddet til start 150 cm over gulvet fås altså 100 målinger i en kørsel. Fotodetektoren er tilsluttet gameporten på pc'en.

Husk, at man aldrig tilsslutter (eller afmonterer) udstyr til en tændt pc!

Du er klar til at måle når...

Du har tændt for støvsugeren til luftpudebanen, vejet vogn og lod, anbragt vognen ved holdemagneten og loddet hænger i ro så højt som muligt.

Du har tændt for pc'en og startet programmet Datalyse. Valgt Smart Pulley Timer som måleapparat og valgt timer.

DU måler...

Afbryd strømmen til holdemagneten, stop vognen med hånden før den når den modsatte ende af banen. (Lav bare et par kvajemålinger!)

Der udføres 4 forsøg:

1. m_{lod} = ca. 10 g og tom vogn
2. m_{lod} = ca. 20 g og tom vogn
3. m_{lod} = ca. 20 g og vogn belastet med 2 lodder á ca. 50g
4. m_{lod} = ca. 20 g og vogn belastet med 4 lodder á ca 50g

Ser grafen rimelig ud, udprintes denne. Vælg **Diff**erentiation i programmet. Herved tegnes (t, v)-grafen på skærmen. Vha. **Regres** tegnes bedste rette linie gennem de målte punkter. Også denne graf udprintes.

Rapporten skal indeholde

- Formål, teori, beskrivelse af forsøget gang,
- EDB-udskrift af ovenstående grafer. (Mindst én af hver type grafer).
- En udfyldning af et skema som vist nedenfor, men lav dit eget skema i din rapport.

Figure E.29 Labguide for air tract (energy conservation, Newton's 2nd law), page 3 of 3.

Forsøgsrække	1	2	3	4
F_{res} / N				
m_{res} / kg				
a_{teori} / $\frac{m}{s^2}$				
a_{eksp} / $\frac{m}{s^2}$				
$\frac{a_{teori} - a_{eksp}}{a_{eksp}} \cdot 100\%$				

Husk et eksempel på alle slags udregninger i rapporten.

Angiv fejlkilder. Husk de vigtigste først! Hvilke fejlkilder vil mindste den målte acceleration?

Vurder forsøgets resultater, altså:

1. Vokser hastigheden lineært som funktion af tiden?
2. Stemmer målt og teoretisk acceleration overens?

Du har måske bestemt både målt og beregnet acceleration med 4 betydende cifre, men alligevel er de kun de to første cifre de samme. Hvordan vil du forklare det?

Electric resistance (Ohm's law)

The aim of the labwork, such as described by the labguide (see figure E.30) is to investigate the resistance of a temperature-independent wire, to investigate if the first law of Ohm $U = R \cdot I$ proves valid when sending current through the wire.

The labwork is done by placing a power supply, a voltmeter, an ammeter and wires in a in the labguide displayed electric circuit. When varying the voltage over the resistance wire, the current is measured.

For the data handling, the voltage is plotted on a graph as a function of the current. The students are asked whether the graph verifies that Ohm's first law is true for the specific resistance wire, and if so, what the resistance is based on the graph.

Additionally, the students are asked to by use the found resistance, the length and diameter of the wire and the formula for the specific resistance

$$\rho = R\frac{A}{L}$$

to determine the specific resistance of wire material and to compare it with a table value.

A number of skills are emphasized in the labwork. For those associated with design, *variable identification* is particularly important, but not really emphasized in the labguide. When measuring, the current is measured as a function of the voltage, but later when plotted, it is the other way around, which could cause an interesting discussion of cause and effect compared to a physical bond between the two quantities. But this is not taken up in the labguide. *Fair test*, *sample size* and *variable types* are not taken up in the labguide.

For the case of those associated with measurements, *relative scale* could play a role for very short or very long wires, but for this case it is expected to play a negligible role. *Range and intervals* are relevant in relation to choosing the number and interval of measurements. *Choice of instrument* could be relevant, since many ammeters and voltmeters need some scale adjustments to display relevant values. *Repeatability* is not addressed. For the case of *accuracy*, they are probably significantly accurate to make sure the students are not puzzled with accuracy. *Uncertainties* are not touched upon.

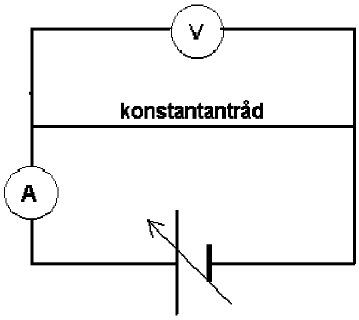
For the case of data handling skills, the students are asked to design an appropriate measuring scheme, display the data on a graph, and fit the data by linear regression, thereby addressing *tables*, *patterns*, *units* and *equation translation*. *Graph type*-considerations are trivial, and *multivariate data* are not relevant.

Finally, for those associated with evaluation, *reliability* is directly addressed in the labguide. *Uncertainties and errors* could be addressed when comparing

Figure E.30 Labguide for electric resistance (Ohm's law), page 1 of 1.

Ohms 1. lov

I denne øvelse undersøges resistansen (modstanden) af en konstantantråd. Vi skal undersøge, om Ohms 1. lov $U = RI$ er opfyldt, når vi sender en strøm gennem tråden.



Der skal bruges:
Spændingskilde, voltmeter, amperemeter samt ledninger m.m.
Lav mindst 10 målinger af strømstyrken I ved forskellige værdier af spændingsforskellen U. Lav selv et resultatskema
Tegn en graf, som viser U som funktion af I.
Viser grafen, at Ohms 1. lov gælder for konstantantråden?
Bestem trådens resistans ud fra grafen.

Eventuelt:

Mål trådens dimensioner: længde L og diameter d (mikrometerskrue, 5 målinger - tag gennemsnit).
Beregn den specifikke resistans for konstantan ud fra formlen

$$\rho = R\frac{A}{L}$$

hvor L er trådens længde, A dens tværsnitsareal. Sammenlign med tabelværdi.

the specific resistance to the table value, and *validity* is not addressed.

Joule's law

The aim of the labwork is - according to the labguide (see figure E.31) to verify Joule's law $\Delta E = R \cdot I^2 \cdot \Delta t$

The labwork is done by placing a resistance coil in a Thermos with water. By monitoring the temperature increase of the water, the current through the coil and the time interval of measurement, Joule's law can be investigated. Two experiments are done. The first keep the time interval of measurement constant, and the latter keeps the current constant. A pre-printed table is given in the labguide to fill out the needed quantities (both measured and derived).

The data handling is done by, for the first experiment, to plot the used energy $\Delta E = m_W \cdot c_W \cdot \Delta T$ as a function of the current squared I^2. For the second experiment, the used energy $\Delta E = m_W \cdot c_W \cdot \Delta T$ is plotted against the time period of measurement Δt. The graphs are to be commented, and on the basis of them the resistance R is to be found for each experiment and are to be compared.

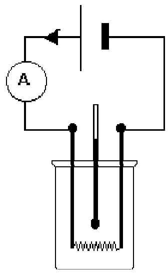
A number of sub-skills are addressed in this labwork. For those associated with design, the students need to be clear about what variables to keep constant and which to vary, which leads on to an understanding of *variable identification* and *fair test*, though explicitly dictated by the labguide. For the case of the *fair test*, the students might be addressed with this if the water amount from each experiment is not kept constant. The *sample size* is determined by the labguide, and is therefore not addressed. *Variable types* are probably not coming up for this labwork.

For those associated with measurement, *relative scale* could come up if the water amount was chosen to be so low that the water started boiling before the time was up or to be so large that the water temperature hardly changed. But it is expected to have been taken care of by the container size and the dictated time intervals and currents. The pre-printed table makes sure the students do not need to address the *range and interval* skills. Depending on the type of thermometer, the students might be aware of the issues related to reading out the temperature, addressing the *choice of instrument*. *Repeatability*, *accuracy* and *uncertainties* will most likely not come up in this labwork, but could have been addressed if the labguide was changed accordingly.

For those associated with data handling, the *tables* and *graph type* are taken care of by the labguide. *Patterns* for sure are relevant for the labwork, as well as *multivariate data* are bound to come up when comparing the two graphs. *Units* will be an issue in writing down the resistance, and *equation translation* will come into play when translating between the fit functions and the physical formulas.

Figure E.31 Labguide for Joule's law, page 1 of 1.

Joules lov



Formålet med øvelsen er at eftervise Joules lov:

$\Delta E = R_{I2}\,\Delta$tid.

Der benyttes den viste opstilling. Apparatur: spændingskilde; termokande; modstandsspiral; termometer 0-50 grader; amperemeter; stopur.
Vi måler temperaturstigningen af vandet i termokanden, når der går en strøm I gennem modstandsspiralen. Herefter beregnes enegiudviklingen kalorimetrisk.
Der udføres to forsøgsserier.
Hold tidsrummet Dtid konstant, mens strømstyrken I varieres. Hold strømstyrken I konstant, mens tidsrummet Dtid varieres. I forsøg 1 kan det være en fordel at skifte vand mellem hver måling. For forsøg 1 tegnes en graf med I_2 på 1.aksen, og ΔE på 2.aksen. I forsøg 2 tegnes en graf med Δtid på 1.aksen, og ΔE på 2.aksen. Kommenter graferne. Bestem R ud fra begge grafer, og sammenlign. T_1 og T_2 er hhv. begyndelses- og sluttemperatur. $\Delta T = T_2 - T_1$

Forsøgsserie 1					
I	Tid	T_1	T_2	m_{H2O}	$\Delta E = mc\Delta T$
A	S	^oC	^oC	kg	J
1,0	60				
1,5	60				
2,0	60				
2,5	60				
Forsøgsserie 2					
I	tid	T_1	T_2	m_{H2O}	Δ E=mcΔ T
A	s	^oC	^oC	kg	J
2,5	60				
2,5	120				
2,5	180				
2,5	240				
2,5	300				

For those associated with evaluation, *uncertainties and errors* are not coming up, whereas when comparing the graphs skills related to *reliability* will be present. *Validity* is not addressed.

E.3.4 Specific labwork activities and their specific purposes (A-level)

Here the four labwork activities determined for the A-level are described and then analyzed in relation to the sub-categories of the procedural skills domain.

Air resistance with cake tins

The aim of the labwork concerning experiments with falling paper cake tins is - according to the labguide of appendix E.32 - to investigate motion affected by air resistance.

Using a distance measurer (as for the free fall experiment) placed at the floor, a paper cake tin is dropped from approximately 2 meters above the distance measurer. By use of a software program, the distance and time is recorded and displayed as a two-column graph. The experiment is repeated with 2, 3, 4 and 5 cake tins on top of each other to keep the cross-section constant but change the mass. The mass and the diameter of the cake tins are measured.

The data is handled by plotting distance as a function of time and doing linear regression on the linear part of the graph. In the theory section, the students are made aware of the two forces acting on the cake tin: the gravity $F_g = m \cdot g$ and the force of air resistance: $F_{air} = k \cdot A \cdot v^2$, where k is recognized as a constant, A being the cross-section of the cake tin and v being the speed. Based on this, the distance versus time graph is to be explained. By use of the linear regression and the measured values of mass and diameter, the air resistance constant k should be determined and compared for each of the experiments.

Investigating the procedural skills, for those associated with design, again the labguide and the apparatus provides the students with the needed information, such that either *variable identification*, *fair test*, *sample size* or *variable types* are necessarily addressed for solving the task.

In precisely the same way, all skills associated with measurements are taken care of.

Then on the other hand, the skills associated with data handling, the students need to address especially *patterns* and *equation translation*, and to some extent *multivariate data*. *Units* might also be an issue, unless the students find only the comparison of the k values important, and not the exact number and unit. This is a reasonable concern, since the students probably have no idea of a valid k value.

For those associated with evaluation, the task does not leave much needed.

Figure E.32 Labguide for air resistance with cake tins, page 1 of 1.

Faldforsøg med tærteform

Formål

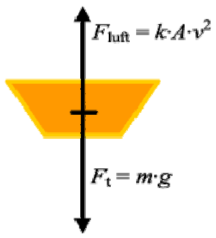
Formålet med forsøget er at undersøge bevægelse med luftmodstand.

Apparatur

LabPro (eller CBL 2), motion detector, Datalyse og tærteforme fra bageren.

Teori

Tærteformen er påvirket af to kræfter:
tyngdekraften $F_t = m{\cdot}g$, hvor m er massen, g er tyngdeaccelerationen og luftmodstanden $F_{luft} = k{\cdot}A{\cdot}v^2$. Her er k er en konstant, A er tærtens tværsnitsareal og v er farten.
På figuren til højre er indtegnet tyngdekraften F_t og luftmodstanden F_{luft} på tærteformen. De to kræfter er modsat rettede, og når bevægelsen er jævn, er de 2 kræfter lige store.

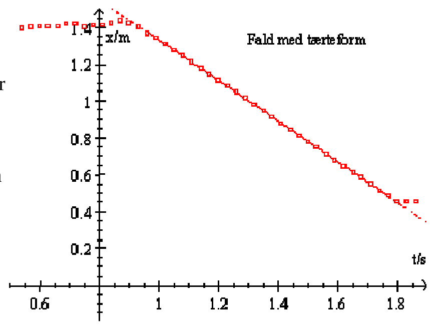


Forsøgsvejledning

Med en afstandsmåler kan man måle afstanden til et legeme. Sonden måler afstanden ved at udsende et lydsignal og måle tiden, fra signalet er afsendt, til signalet er reflekteret til sonden. Ved at udsende signaler fx hvert 0,03 sekund kan man få løbende værdier af afstanden fra sonde til legeme. Sonden måler afstanden til nærmeste legeme inden for en rumvinkel på 20° og inden for afstande fra ca. 0,40 m til ca. 6 meter.
Sonden anbringes på gulvet, og tærteformen holdes ca. 2 meter over sonden. LabPro styres fra Datalyse. I Datalyse vælger man LabPro som apparat og vælger »Måling (t, f(t))«. Indstil fx antal målinger til 100 og tid pr. måling til 0,03 sekund og vælg afstandsmåling. Når LabPro måler afstand, giver sonden et klik for hver måling. I praksis kan målingen derfor foretages ved at en person sidder ved pc'en og styrer Datalyse, og en anden person holder tærteformen. Når sonden begynder at klikke, slippes tærteformen.
Foretag forsøg med 2, 3, 4 og 5 kageforme inden i hinanden. Husk, at bestemme masse og diameter af tærteform.

Behandling

Vælg lineær regression i Datalyse og bestem herved hastigheden af formen, når bevægelsen er blevet jævn. Diskuter selv den fysiske situation og forklar grafens udseende. Hver enkelt del af grafen beskrives!
Benyt de målte værdier til at udregne konstanten k for alle forsøg og undersøg, om k bliver den samme.



Projectile motion

This labwork aims at investigating the projectile motion. A copy of the labguide can be found in appendix E.33.

The labwork is done by firing a steel sphere from a spring canon on to a distant horisontal carbon paper to detect the firing distance for different firing angles. The carbon paper is attached to a screw jack to make sure the height of the firing outlet and the point of impact is equal. At impact the steel sphere it will leave a mark on the carbon paper, which can be used to detect the fly width of the sphere. The experiment is repeated three times for a number of firing angles in the interval of 20-70 degrees. Finally the firing speed of the sphere is measured by setting the angle to 90 degrees (vertical shot), and the travel height is detected.

For the data handling, first the firing speed is found by use of

$$\begin{aligned} 1/2mv_0^2 &= mgh \\ v_0 &= \sqrt{2gh} \end{aligned}$$

Then the mean of the three repeated measurements for equal angles are found and compared to the theoretically predicted value

$$x_{max} = \frac{v_0^2 \sin 2v}{g}$$

where v_0 is the initial velocity and v is the firing angle. The found values of x_{max} are plotted in a coordinate system as a function of $\sin 2v$. The students are to argue for the expectance of a straight line with the slope of v_0^2/g and to investigate how this fits with the measurements.

For this labwork, the students probably need to identify the firing angle as the independent variable and the fire distance as the dependent variable to understand the labwork, thereby setting *variable identification* on their agenda. *Fair test* and *sample size* are as the labwork is designed not relevant skills. Also *variable types* are most likely not touched upon.

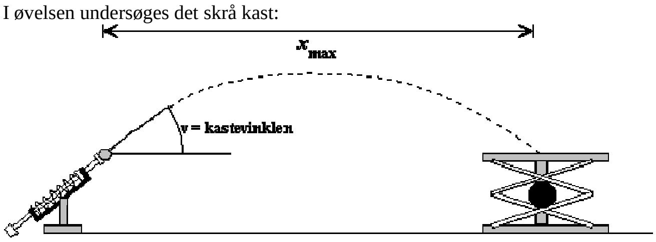
For those associated with measurements, *relative scale* will not be addressed, whereas *range and intervals* on the other hand will come into play, since the students need to decide on the number and spread of the angles for measurements. A number of instances in this labwork force the students to consider *choice of instrument*, e.g. the uncertainty of measuring distance and the different points of impact for unchanged conditions, where the latter is confronting *repeatability*. *Accuracy* could come into play for the same reasons. The labwork holds the potentials of discussing *uncertainties*, but are so far not addressing these issues.

For those associated with data handling, the students need to confront the skills of *tables* in designing a measuring scheme. The choice of *graph type* is

Figure E.33 Labguide for projectile motion, page 1 of 1.

Skråt kast

I øvelsen undersøges det skrå kast:



Vi gør det ved at eftervise formlen for den maksimale kastelængde:

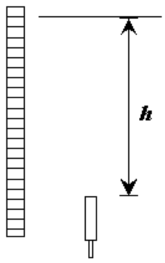
$$x_{max} = \frac{v_0^2 \sin(2v)}{g}$$

Her er v0 begyndelseshastigheden og v kastevinklen (elevationen).

Apparatur:
Fjederkanon, stålkugle, lineal eller målebånd, karbonpapir, "donkraft".

Udførelse:
Donkraften indstilles, så den er i samme højde som kuglen i affyringsøjeblikket. Man prøver sig frem med et par affyringer, og donkraften placeres, så kuglen lander på den hver gang. På donkraften lægges et stykke hvidt papir med carbonpapiret over. Begge dele skal sidde forsvarligt fast. Derefter affyres kuglen, og ved hjælp af målebåndet kan man bestemme kastevidden ved at måle afstanden fra kanonen hen til de mærker, som carbonpapiret har afsat på det underliggende papir. Forsøget udføres med et antal kastevinkler i intervallet 20o til 70o. Der udføres tre forsøg med hver kastevinkel. Til sidst bestemmes begyndelseshastigheden v0. Kastevinklen stilles til 90o, og der foretages et par affyringer. Vendehøjden for kuglen bestemmes så præcist som muligt. Begyndelseshastigheden kan da beregnes, idet kuglens kinetiske energi omsættes til potentiel energi:

$$\frac{1}{2} m v_0^2 = mgh \Leftrightarrow v_0 = \sqrt{2gh}$$



Resultatbehandling:
For hver kastevinkel beregnes middelværdien af måltallene, og det undersøges, om tallene stemmer med formlen for xmax.
De målte værdier af xmax afbildes i et koordinatsystem som funktion af sin(2*v*). Begrund, at grafen bør være en ret linje med $\frac{v_0^2}{g}$ som hældningskoefficient, og undersøg, om det stemmer.

straight-forward and therefore not addressed, whereas *patterns* for sure are when interpreting the graph. As was the case of *fair test*, *multivariate data* are not addressed. Some working with *units* come into play, and for the interpretation of the graph fit, *equation translation* are practiced.

For those associated with evaluation, *uncertainties and errors* are in this labwork not taken up, but the labwork hold the potential to do so. *Reliability* is investigated in comparing the measured values to the theoretically predicted, whereas *validity* is not addressed.

Momentum

This labwork concerning momentum and central collisions has the aim of studying elastic and inelastic central collisions and to investigate whether the momentum and energy are conserved. The labguide can be found in appendix E.34.

The labwork is done on an air track with two carts with appurtenant flags. Two photo cells are placed such that when the flags pass by the photo cells, the speed of each cart can be measured both before and after the collision. A (large) number of elastic and totally inelastic collisions are done for different masses of either cart.

Based on the velocities and masses, the momentum and kinetic energy before and after the collision are calculated for both carts. Care is asked to be given to the sign of the velocities. The students are asked to investigate if the momentum and kinetic energy are conserved for the different types of collisions. Energy conservation is tested by calculating the relative deviation for the total kinetic energy before and after the collision. Conservation of momentum can be done in the same way, but according to the labguide, this is hardly realistic to gain good results. A table is provided for data for both elastic and in-elastic collisions.

For this labwork, some procedural sub-skills are addressed. For those associated with design, *variable identification* is not a large issue, since it is taken care of by the labguide. In the same way, *fair test*, *sample size* and *variable types* are not addressed.

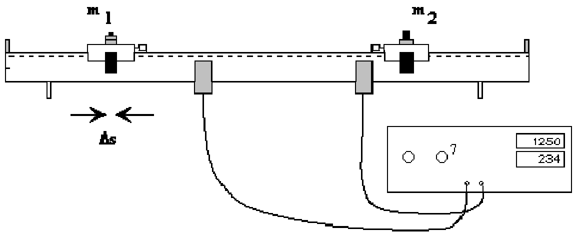
For those associated with measurement, *relative scale* and *range and intervals* are not addressed. *Choice of instrument* could be addressed in relation to understanding the imprecision of the derived data. *Repeatability* is obviously not addressed, since each collision will be different. *Accuracy* and *uncertainties and errors* will be relevant in relation to the data interpretation.

For those associated with data handling *tables* are somewhat addressed, though a possible table for the data and the further data handling is printed in the labguide. No graphs are drawn for this labwork. For the case of *patterns*, hopefully the students will notice how the energy before is larger than after and connect this to the sources of errors. Since each experiment is related only to itself, the students should have no issues of *multivariate data*. *Units* are pretty

Figure E.34 Labguide for momentum, page 1 of 1.

Centralt stød

Formålet med øvelsen er at studere elastiske og uelastiske, centrale stød, og undersøge, hvorvidt impuls og energi er bevaret.



Forsøget udføres på luftpudebane med to vogne, fotoceller, tæller og lodder. De to vognes masser betegnes m_1 og m_2 , hastighederne før stødet betegnes u_1 og u_2 og hastighederne efter stødet v_1 og v_2. Hastighederne regnes med fortegn - bestem selv, hvilken retning, I regner som den positive. Vognenes hastigheder bestemmes ved at måle fanebredden Δs og den tid t, det tager fanen at passere fotocellen. Der gælder da

$$\mathbf{v=\Delta s/t}$$

Der udføres et (stort) antal elastiske og fuldstændig uelastiske stød - både, når vognene har samme masse og når de har forskellig masse. I hvert stød beregnes impuls og kinetisk energi før og efter stødet. Undersøg, om impuls og kinetisk energi er bevaret i de forskellige typer af stød. I kan også gennemføre undersøgelse af uelastiske stød, som ikke er fuldstændig uelastiske; det er vanskeligere rent forsøgsteknisk.
Energibevarelsen kan undersøges ved at beregne den relative afvigelse mellem $E_{kin,før}$ og $E_{kin,efter}$.
Det er næppe fornuftigt at vurdere impulsbevarelsen på denne måde (prøv).
Forslag til resultatskema: (ét til elastiske, ét til uelastiske)

			Før				Efter			
Forsøg	m_1	m_2	t_1	t_2	u_1	u_2	t_1	T_2	v_1	v_2
nr.	kg	kg	s	s	m/s	m/s	s	S	m/s	m/s
1										
2 (osv)										

... (tabel fortsættes)

$P_{før}$	P_{efter}	$E_{k,før}$	$E_{k,efter}$	afv. i P	afv i E_{kin}
kgm/s	kgm/s	J	J	%	%

much taken care of by the table, and *equation translation* is not dealt with.

On the other hand, for those associated with evaluation, *uncertainties and errors* as well as *reliability* are addressed.

Uniform circular motion

The labwork concerning the uniform circular motion (see labguide at figure E.35-E.36) aims for verifying that the centripetal force of a body in a uniform circular motion is given by

$$F_c = \frac{4 \cdot \pi^2 \cdot m \cdot r}{T^2} \tag{E.5}$$

where m is the mass of the body, T is the period of the circular motion and r is the radius of the motion.

By use of special setup a motor spins a vertical stick with variable speed. Attached to the spinning stick is a vertical dynamometer, again attached to a string over a pulley on to a cart, which is what is doing the horizontal circular motion. See the labguide for a sketch. Turning on the motor and allowing the motion to be uniform, the radius and the period is detected, and the force from the dynamometer is read out. The period is determined by counting of 50 turns. The experiment is repeated a number of times with other values of the radius. Thereafter the mass of the cart is changed, and the same measurements are done.

All data is noted in a pre-printed scheme, and by use of the equation and the measured periods, radii and masses, the measured and the calculated forces are found. The uncertainty of the measured centripetal force is estimated to be equal to the read-out values just above or below the measured values. The uncertainty of the calculated force, the labguide states, is

$$\frac{\Delta F_{calc}}{F_{calc}} = \frac{\Delta r}{r} \tag{E.6}$$

where Δr is the read-out uncertainty of the radius. The labguide states, that if

$$|F_{calc} - Fmeasure| \leq \Delta F_{calc} + \Delta F_{measure} \tag{E.7}$$

then the equation is verified. No further explanation of this uncertainty calculation is given.

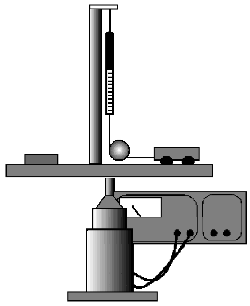
For this labwork, for those skills associated with design, *variable identification* for sure comes into play, since the students need to juggle between a number of quantities, which has a physical bond which does not allow them to clearly understand what is the dependent and independent variables. Also they operate with derived and directly measured quantities, which are to be compared. By doing this, the labguide makes sure the students do not have issues with *fair*

Figure E.35 Labguide for uniform circular motion, page 1 of 2.

Jævn cirkelbevægelse

Øvelsens formål
er at eftervise, at centripetalkraften på et legeme, der udfører en jævn cirkelbevægelse, er givet ved formel 1:

$$F = \frac{4 \cdot \pi^2 \cdot m \cdot r}{T^2}$$



formel 1:
hvor *m* er legemets masse, *T* omløbstiden for cirkelbevægelsen og *r* er radius i bevægelsen.

Opstilling
Vi benytter en eksperimentermotor (figur 1) til forsøget. Her kan vi på Dynamometret aflæse centripetalkraften og på linealen på skinnen kan vi måle cirkelbevægelsens radius.

Forsøgsgang
Motoren startes. Omdrejningshastigheden reguleres på spændingskilden, så en passende radius opnås. Når Dynamometret er faldet til ro, aflæses kraftens størrelse. Omløbstiden bestemmes ved måling af 50 omløb. I kan eventuelt benytte jer af en MC24 tæller og en fotocelle. Motoren standses. Vognen trækkes nu ud så kraftmåleren viser det samme som før. Radius i banen kan nu aflæses. Forsøget gentages 34 gange med andre værdier af radius. Derefter ændres vognens masse ved hjælp af lodder, og forsøget gentages som ovenfor beskrevet med den ny masse.
Massen af vogn og lod(der) bestemmes ved vejning. Alle måltal indføres i et oversigtsskema.

M	*T*	F_m	F_b	ΔF_m	ΔF_b	

Figure E.36 Labguide for uniform circular motion, page 2 of 2.

I dette skema er kraften F_b beregnet af formel 1. F_m er den målte værdi af kraften. Endvidere er der angivet usikkerheden på disse størrelser.

Usikkerheden ΔF_m på den målte kraft F_m sættes til 1 streg på dynamometeret. Usikkerheden på den beregnede kraft F_b findes af følgende simple udtryk

formel 2: $$\frac{\Delta F_b}{F_b} = \frac{\Delta r}{r}$$

hvor Δr er usikkerheden på bestemmelsen af radius r. Hvis der gælder

$$|F_b - F_m| \leq \Delta F_m + \Delta F_b$$

har vi eftervist udtrykket i 1)

test, though having a number of variables in play, which are not controlled. On the other hand, *sample size* is taken care of by the labguide.

For those associated with measurement, the *relative scale* is not addressed, whereas *range and intervals* could be an issue. Due to the complexity of the many variables, one could by chance change the period and radius in such a way the centripetal force would not significantly differ. The *choice of instrument* is important in this labwork, since both the accuracy of the dynamometer and the radius readout play a significant role. By asking the students to count out 50 turns to determine the period, the students most likely have time to investigate any 'wobbly' motion of the cart, thereby giving some insight to the *repeatability*. *Accuracy* and *uncertainties* are playing a role, though only engaging in the randomness of the uncertainties.

For those associated with data handling, *tables* are taken care of by the labguide, and *graph types* are obviously not relevant. *Patterns* could be an issue, though the error analysis does not push forward noticing if either of the two methods of determining the centripetal force gives larger values. *Multivariate data* could be a significant issue for this labwork, but the hurdles are elegantly removed. The students do need to juggle some *units*, whereas *equation translation* is not relevant.

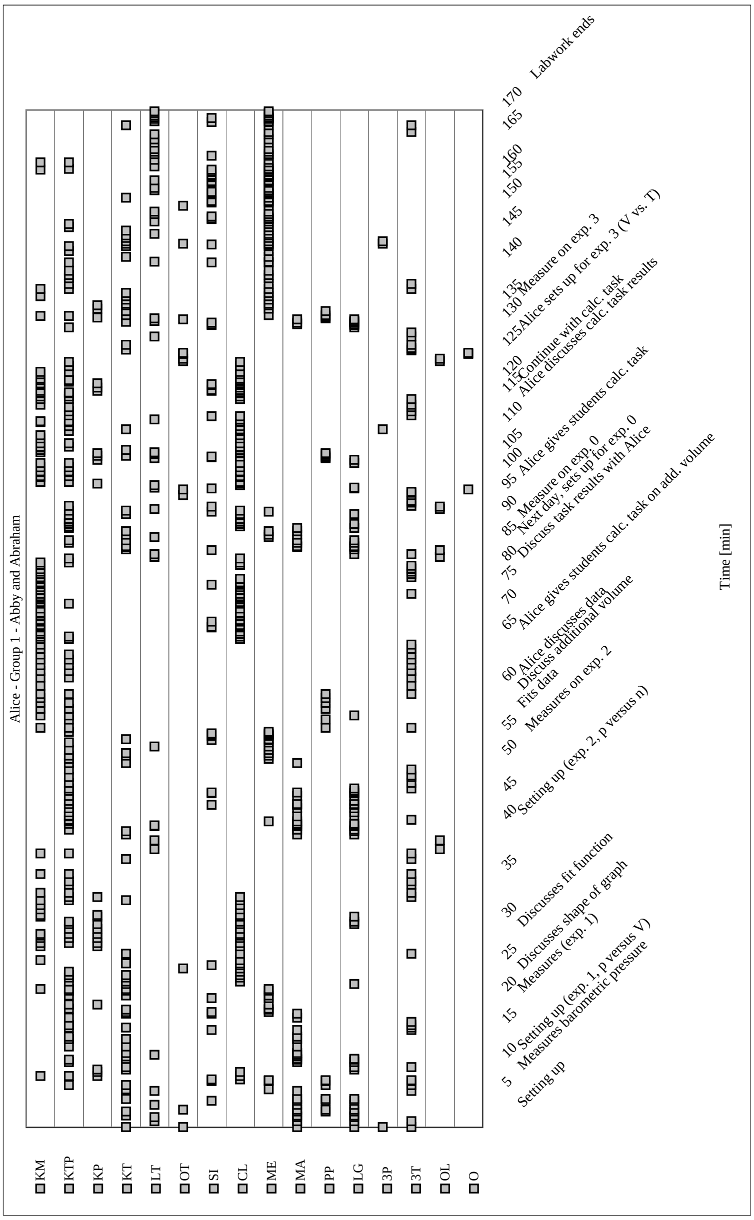
Finally, for those associated with evaluation, *uncertainties and errors* are to a larger extent than in any other of the labwork activities in play, and it is related to the *reliability* in a somewhat simplistic way. *Validity* is not addressed.

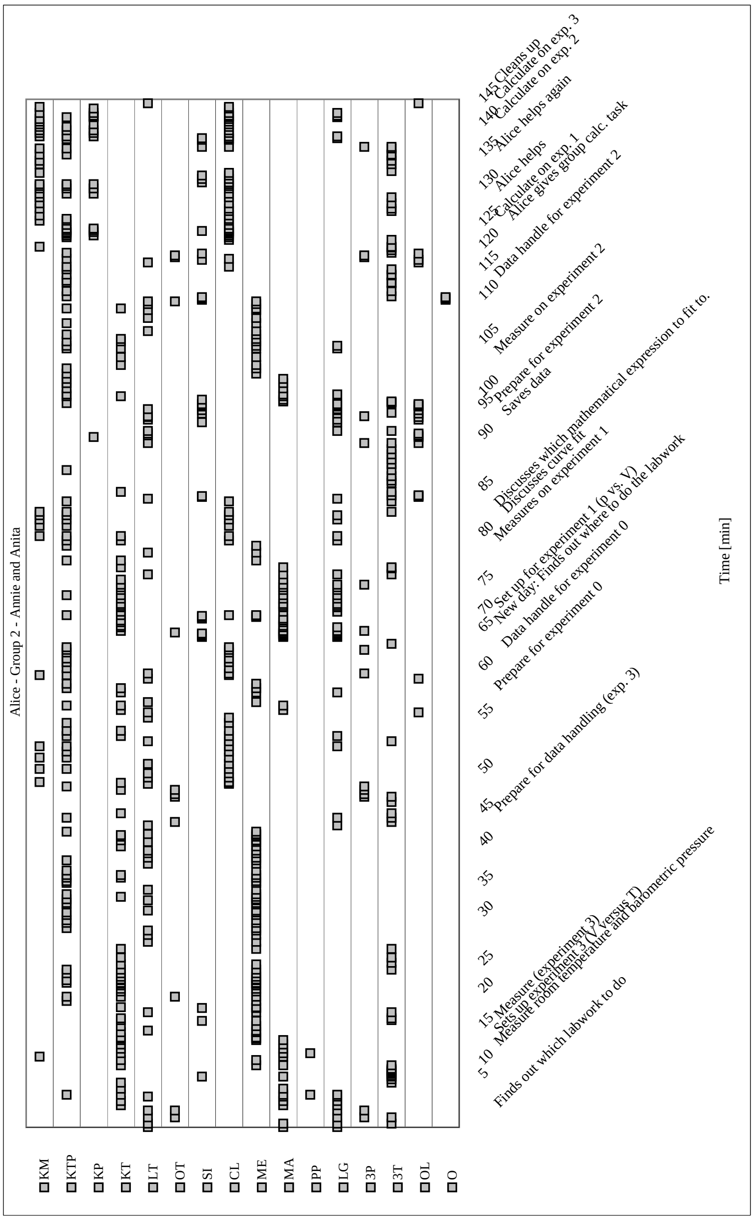
F CBAV - category based analysis of videotapes

F.1 CBAV - the tool

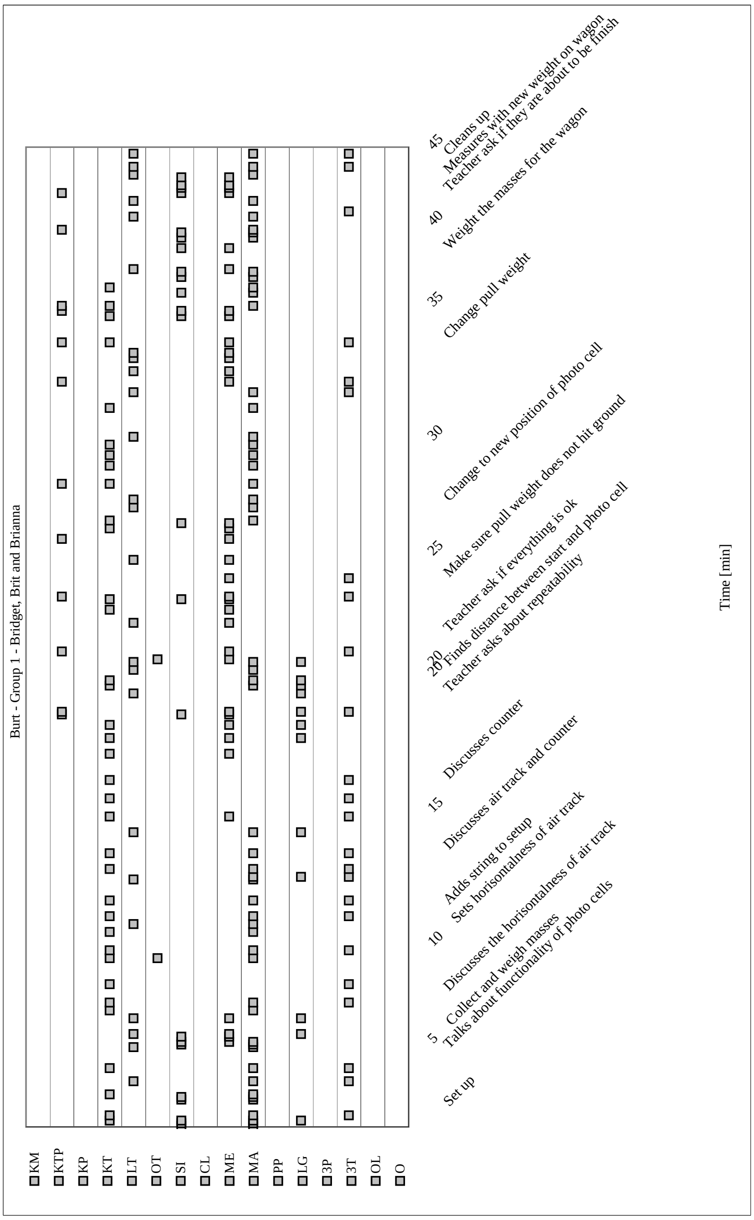
Category		*Description*	*Examples*
Other	O	Activities not related to the lab	Talking about last TV
Other related to labwork	OL	Activities related to labwork not included in the other categories	Looking for the labguide
Interacting with a third person	3P	A third person can be the teacher, the tutor, other students, or similar	Tutor helps to solve a problem and talks to the students
Labguide	LG	Using the labguide	. . . to plan what to do.
Paper and pencil	PP	Using paper-and-pencil. Students are writing or reading in their own notes.	Preparing tables for measurement data, drawing a graph.
Manipulation of apparatus	MA	Using the apparatus and devices. Carrying out experimental set up or preparing a measurement	Building up an electrical circuit; taking a test-measurement; having problem with the apparatus.
Discussing apparatus	DA	Discussing results of manipulation of apparatus	Discussing test-measurement, discussing functionality of setup
Measurement	ME	Using the apparatus to gather data and writing them down. Resources used are apparatus *and* paper/pencil	Taking the pendulum's amplitude and writing the value down.
Discussing measurement	DM	Discussing results of measurements	Discussing the reasonability and trustworthiness of the measured data
Calculation	CL	Using a (pocket) calculator or a specific software like Excel for this purpose or doing a direct calculation with paper-and-pencil	Calculating a physics quantity from the measurement data

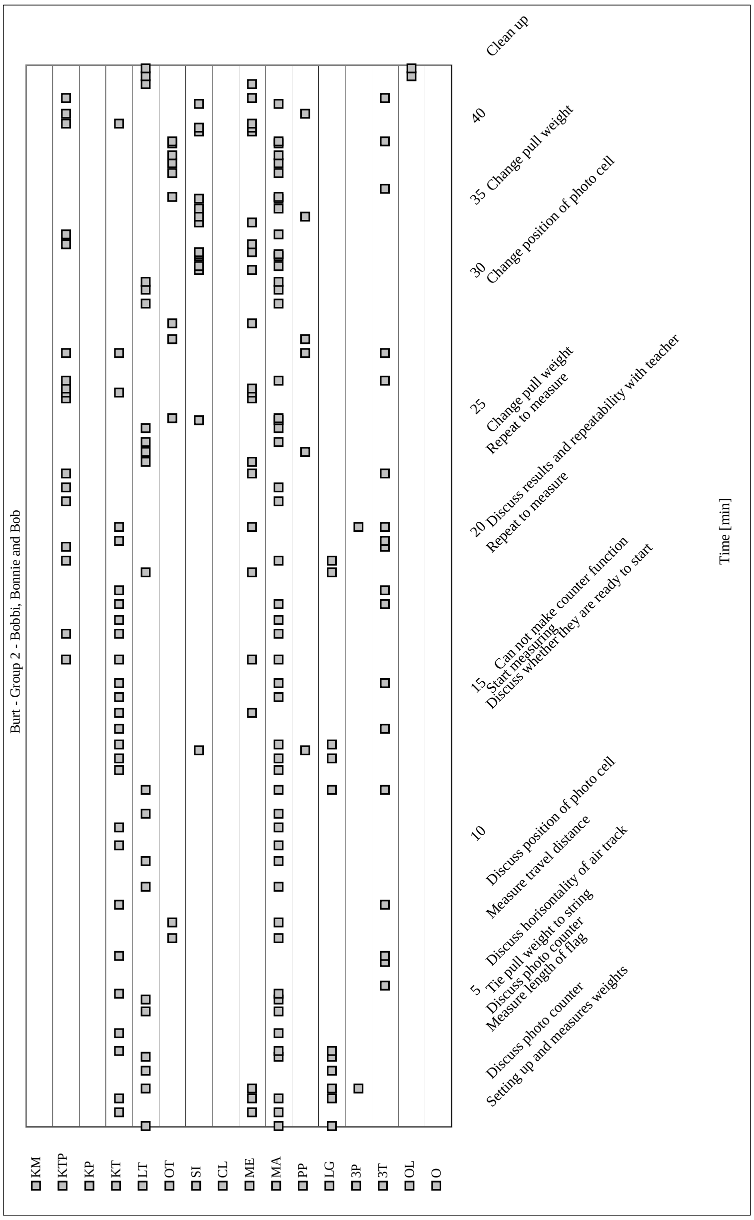
F.2 CBAV - the diagrams

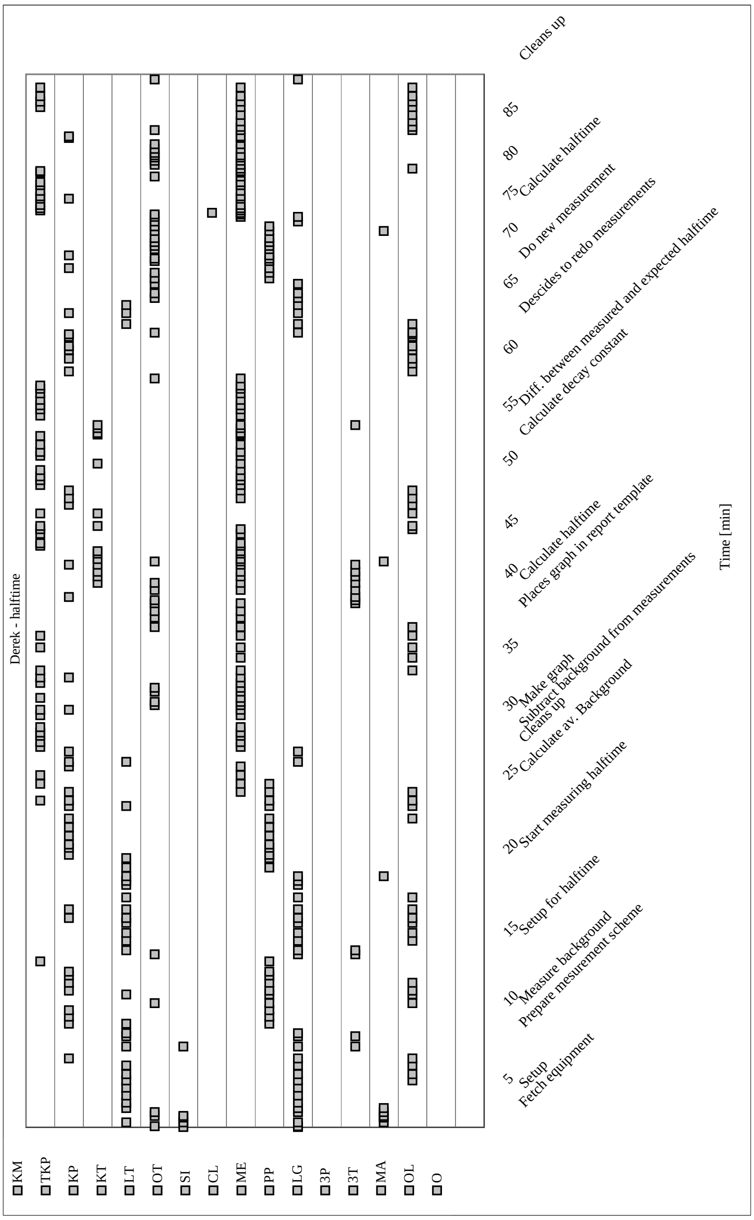

Alice - Group 1 - Abby and Abraham
KM
KTP
KP
KT
LT
OT
SI
CL
ME
MA
PP
LG
3P
3T
OL
O
Time [min]
Setting up
Measures barometric pressure
Setting up (exp. 1, p versus V)
Measures (exp. 1)
Discusses shape of graph
Discusses fit function
Setting up (exp. 2, p versus n)
Measures on exp. 2
Fits data
Discuss additional volume
Alice discusses data
Alice gives students calc. task on add. volume
Discuss task results with Alice
Next day, sets up for exp. 0
Measure on exp. 0
Alice gives students calc. task
Alice discusses calc. task results
Continue with calc. task
Alice sets up for exp. 3 (V vs. T)
Measure on exp. 3
Labwork ends

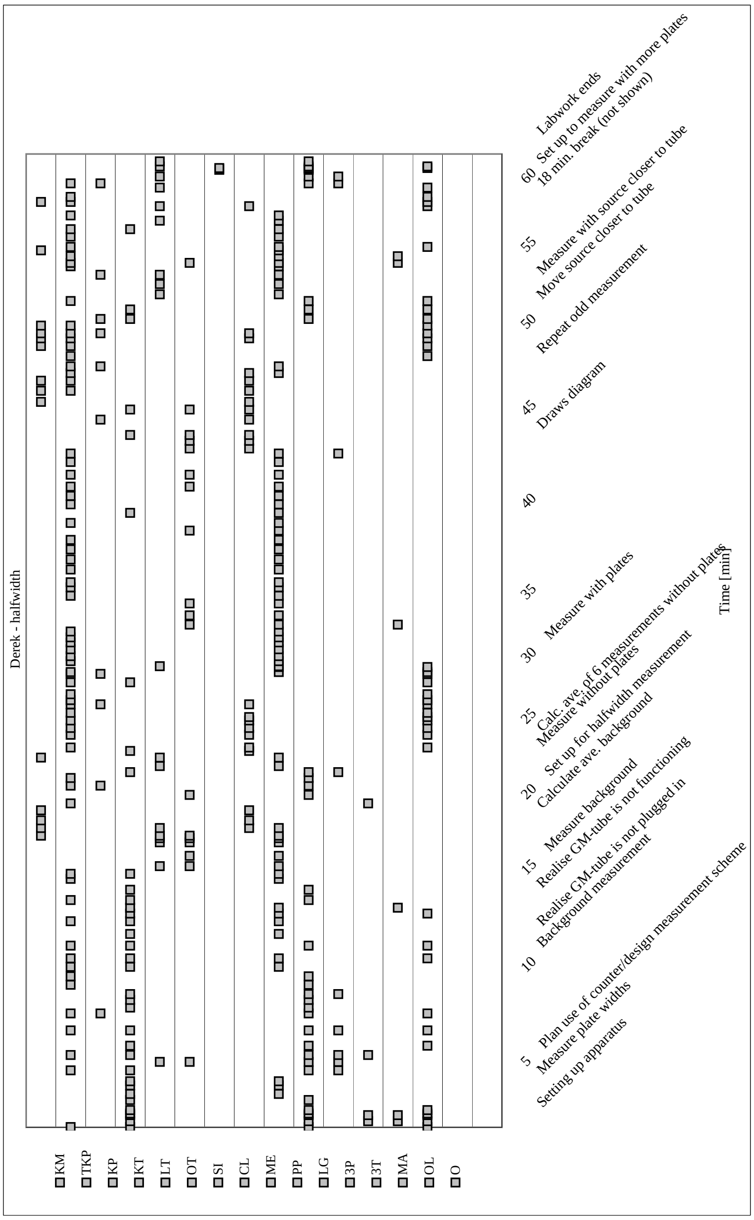


Alice - Group 2 - Annie and Anita
KM
KTP
KP
KT
LT
OT
SI
CL
ME
MA
PP
LG
3P
3T
OL
O
Time [min]
Finds out which labwork to do
Measure room temperature and barometric pressure
Measure (experiment 3)
Prepare for data handling (exp. 3)
Prepare for experiment 0
Data handle for experiment 0
New day: Finds out where to do the labwork
Measures on experiment 1
Discusses curve fit
Discusses which mathematical expression to fit to.
Saves data
Prepare for experiment 2
Measure on experiment 2
Data handle for experiment 2
Alice gives group calc. task
Calculate on exp. 1
Alice helps
Alice helps again
Calculate on exp. 2
Calculate on exp. 3
Cleans up


Burt - Group 1 - Bridget, Brit and Brianna
KM
KTP
KP
KT
LT
OT
SI
CL
ME
MA
PP
LG
3P
3T
OL
O
5
10
15
20
25
30
35
40
45
Set up
Talks about functionality of photo cells
Collect and weigh masses
Discusses the horisontalness of air track
Sets horisontalness of air track
Adds string to setup
Discusses air track and counter
Discusses counter
Teacher asks about repeatability
Finds distance between start and photo cell
Teacher ask if everything is ok
Make sure pull weight does not hit ground
Change to new position of photo cell
Change pull weight
Weight the masses for the wagon
Teacher ask if they are about to be finish
Measures with new weight on wagon
Cleans up
Time [min]


Burt - Group 2 - Bobbi, Bonnie and Bob
KM
KTP
KP
KT
LT
OT
SI
CL
ME
MA
PP
LG
3P
3T
OL
O
Setting up and measures weights
Discuss photo counter
5
Measure length of flag
Discuss photo counter
Tie pull weight to string
Discuss horisontality of air track
Measure travel distance
Discuss position of photo cell
10
15
Discuss whether they are ready to start
Start measuring
Can not make counter function
20
Repeat to measure
Discuss results and repeatability with teacher
Repeat to measure
Change pull weight
25
30
Change position of photo cell
35
Change pull weight
40
Clean up
Time [min]


Derek - halftime
KM
TKP
KP
KT
LT
OT
SI
CL
ME
PP
LG
3P
3T
MA
OL
O
5 Setup
Fetch equipment
10 Measure background
Prepare mesurement scheme
15 Setup for halftime
20 Start measuring halftime
25 Calculate av. Background
30 Make graph
Subtract background from measurements
Cleans up
35
40 Calculate halftime
Places graph in report template
45
50
55 Diff. between measured and expected halftime
Calculate decay constant
60
65 Descides to redo measurements
70 Do new measurement
75 Calculate halftime
80
85
Cleans up
Time [min]


Derek - halfwidth
KM
TKP
KP
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60
Time [min]
Setting up apparatus
Measure plate widths
Plan use of counter/design measurement scheme
Background measurement
Realise GM-tube is not plugged in
Realise GM-tube is not functioning
Measure background
Calculate ave. background
Set up for halfwidth measurement
Measure without plates
Calc. ave. of 6 measurements without plates
Measure with plates
Draws diagram
Repeat odd measurement
Move source closer to tube
Measure with source closer to tube
18 min. break (not shown)
Set up to measure with more plates
Labwork ends