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ON MATHEMATICS AND WAR
An essay on the implications, past and present, of the military involvement of the mathematical sciences for their development and potentials

Translated and updated in 1988/1992
by Jens Høyrup for the volume

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from

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Print prepared for the meeting

Mathematics and War

The Impact of Mathematical Thinking and the Application of Mathematical Methods

Co-development of Mathematics and the Means of War

Karlskrona (Sweden), August 29–31, 2002

Introduction

For several decades, the involvement of the sciences with war has been a key theme in radical debates about the nature of science and the role of the scientific community and establishment – next, perhaps, to only the discussion of the responsibility of the sciences for engendering the ecological crisis.

The following essay belongs within this tradition, as illustrated by its history. A first, incomplete version was presented in 1982 at a symposium on "Military influences on the sciences and military uses of their results" held in Oldenburg, Western Germany, in memory of Carl von Ossietzky (co-founder of War Resisters International in 1922, and awarded with the Nobel Prize for Peace in 1936 while a concentration camp prisoner). A full German version was published in 1984 by Bund demokratischer Wissenschaftler (West German branch of the World Federation of Scientific Workers, and thus a post-Hiroshima-organization).

Apart from links to the war-resisting aftermath of the two World Wars, the article was thus connected to the debate on the Euromissiles, which was particularly intense in Western Germany during the early 1980es, and further to the discussions of the first strike strategy of the Reagan strategists (the memorable "decapitation of the Soviet hen").

The essay takes it for granted that the sciences, and not least mathematics, are important for the waging of a modern war. This is a point which once needed to be made, but which *has* been made amply since the 1960es, and which, moreover, has no clear implications as to *what should be done*. Instead, questions are taken up which have such implications for various subgroups within the mathematical community, even though they may seem rather academic for others. Some mathematicians, indeed, have deserted their science in the conviction that it was corrupt through and through, socially as well as epistemologically; we ask whether this is true, trying to sort out the various senses in which it may be true or false. Others suppose that their science can only thrive (for epistemological or for trite financial reasons) if it is intimately connected with the military sector, and are willing to take the necessary risks in the interest of their field and profession; so, as a matter of fact, are quite a few members of any profession, but what we can do in the present context is to analyze whether the assumed necessary condition is really necessary for the prosperity and well-being of this specific field – trying, once again, to sort out meanings in order to make possible the formulation of precise answers. Still others simply strive to build up insights which are deep and precise enough to allow fruitful debate with colleagues and efficient political action within and by means of their science and profession.

The essay has two authors (thus the "we" of the preceding paragraph). One (Bernhelm Booß-Bavnbek) is a mathematician with strong interest in the relation between mathematics and its uses, including the philosophical aspect of this question; the other (Jens Høyrup, author of this introduction) is a historian of mathematics with an outspoken philosophical and sociological bent. Both authors share political commitment to the question, and the same fundamental stance; this did not prevent us from heated discussions over the content and formulation of at least every third paragraph; no single phrase was written, however, before we had come to an agreement on the point involved.

The English revised translation was prepared by me in 1988 as a contribution to the Sixth International Congress of Mathematics Education, Special Day on Mathematics, Education and Society. On that occasion, I attempted to weigh our original conclusions against the central events of the intermediary four years. I made no effort to update our statistical information, which had only been meant to create a basis for our theoretical discussions; the aim of the revision was rather to increase the precision of these.

Over the years, Bernhelm Booß-Bavnbek and I had collected and discussed material pertinent to this partial revision. However, during the phase when the translation was formulated we had very little opportunity to collaborate, and the text as it was then formulated was thus entirely my responsibility though not my merit; it may not at all points have corresponded to what my co-author would have said.

Since 1988 another four years have passed, and the political geography of our world has changed. A proposal (made in Chapter 6) to "consider the implications of [the military employment of mathematicians], concentrating upon the situation of mathematicians of our own block – those of the socialist countries [being] in a better position to assess their own dilemmas" is outdated, since the "other" block and the Soviet Union have lost the Cold War and do not exist any longer. Trying to camouflage the original context of the essay through removal of such phrases would be dishonest, I felt. Attempting to update statistical information would be without purpose, and replacing the original references to a specific political condition with others of equal precision would be impossible, given the instability of our actual situation[1].

If questions of *war in general* had been obsolete, and not only those raised by *this particular* (cold) war, republishing the study would have been an expression of grotesque nostalgia. But they seem not to be. During a surgical operation involving carpet bombing and other blunt instruments, some hundred to three hundred thousand persons were killed in Iraq in early 1991. March 8, 1992, the *New York Times* leaked a Pentagon plan to conserve World hegemony and to avoid the emergence of any competing global or regional power; even though the paper in its actual formulation may be meant as an electioneering manoeuvre, part of its substance is certainly honest.

Bellicose *ideologies*, moreover, appear to be stronger than ever since the sixties. How else should we explain, e.g., this advertisement from *Evening Standard* (October 9, 1990, p. 32) directed not at potential members of the British Volunteer Reserve Forces but at their employers:

> LEADERS AREN'T BORN EVERY DAY. JUST AT THE WEEKEND.
>
> Before you can become a leader, you need to experience responsibility.
>
> In the Volunteer Reserve Forces, men and women are given the opportunity to take control of challenging situations early in their careers.
>
> It's an essential part of their training.
>
> As their confidence grows, they grow as leaders. And this will show in their civilian jobs. As an employer you will certainly notice.
>
> [etc.]

Or how explain that Time-Life Books makes a special offer just after the Iraq

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[1] As illustrations of these uncertainties, as they look at this very moment of writing (March 20, 1992): It is discussed in the European press whether President Bush is most likely to attack Libya or Iraq in a predicted attempt to improve his opinion poll ratings, and the optimists among us discuss whether he is really going to attack; elsewhere on the globe it is a serious question whether Ukraine and Russia, formally members of a confederation, are actually moving toward a terror balance on atomic weapons.

When this book appears, the reader will certainly know the answers. Undoubtedly, new questions will have arisen.

War, allowing the recipient of their colourful envelope to sign the statement "YES! I want to explore the new frontiers of modern warfare. Please send me **Special Forces and Missions** [etc.]"?

Everybody looking around will be able to find both preparation of actual war and evidence for militarization of dominant media and business culture. Which wars, and which reflections, may depend on the date; but nothing suggests that the main trends will change on short notice.

Nor is there any reason to believe that scientists and mathematicians are not, or will not be involved in the development of new weapons and new tactics and strategies.

These observations are the background for the republication of a study whose concerns appear unfortunately to be less outmoded than some of its actual formulations. Since useful updating seems not to be possible, I have preserved the text as it was formulated in the translation of 1988. It is left to the reader (and it may be a sound exercise in times like these) to reflect critically upon the text, and to disentangle whatever still valid theoretical understanding it may contain from formulations referring to a world that has now disappeared.

ON MATHEMATICS AND WAR
An essay on the implications, past and present, of the military involvement of the mathematical sciences for their development and potentials

Dedicated to
HORST-ECKART GROSS
Mathematician, champion of comprehensive understanding,
Berufsverbot in the Federal Republic of Germany
and to
JOHN LAMPERTI,
Statistician, "counter-expert"

The following examines the relation between mathematics and the trade of war. This question has a double interpretation. One may ask for the importance of mathematics for armament and war. Or one may explore the importance of armament and war for mathematics.

The first problem is only dealt with as a subordinate theme in the following. We all know that the modern military business consumes every nourishment within its reach: Science, money, people, etc. We also know that modern warfare and its preparation build intensively on advanced technology, and thus, under the conditions of the ongoing scientific-technological revolution, on scientific knowledge and information. We know, finally, that modern science and modern technologies (including many socio-technologies, which also find military application) are thoroughly mathematicized.

Instead, we shall turn our attention to the second problem: the implications for the sciences, especially the mathematical sciences, of their military involvement[1]. The problem may briefly be so formulated, whether mathematics

[1] When mathematics is spoken about in the following, mathematics *as a science* is thus intended, i.e., the creation of new theoretical knowledge. Mathematics as a subject for teaching and as a means for applications will mostly be considered only *in their connection* to mathematical science or to the community of mathematical scientists.

I. ... that the modern military business consumes every nourishment ...

Missile control, e.g, consumes systems theory and control theory, i.e., group 93 of the *Mathematical Reviews*. In civilian life, these theories are also used for process control in chemical plants, breweries, rolling mills, in the construction of industrial robots, and for optimizing measuring instruments.

Looking through the keywords used in this group during one year (1981), one encounters the following concepts recurrently: approximation, autoregulation, boundary condition, characteristic, convergence, correction, correlation, curvature, difference equation, differential equation, dimension, distribution, eigenfunction, error, filter, frequency, graph, harmonic linearization, information, nonlinearity, order, parameter, perturbation, phase space, probability, process, randomness, singularity, stability, state, steering, symmetry, time lag, transition process, turbulence, variable.

An array, indeed, which points to an abundance of consumed disciplines.

is paid in good or counterfeit coin when prostituting itself to the military sector. Without metaphor: Is the production of mathematical knowledge, and the overall progress of mathematical science, furthered or impeded by the military involvement of mathematics?

At first the question is approached by means of a ladder of historical steps. Chapter 1 presents the phenomenology of the past, i.e., the factual development of the connections between mathematics and military concerns through the eighteenth century, concentrating upon a set of paradigmatic examples. Chapter 2 discusses the basic structures which appear to materialize from this pre- and Early Modern phenomenology. Chapter 3 deals with the "prelude" to the scientific-technological revolution in the nineteenth century: The attempt, made in the French revolutionary wars, to wage war on a scientific basis; and the creation of the preconditions for the later science-based reconstruction of broad societal practices – preconditions involving the sciences, general and specialists' education, technology, and social, economic and political structures.

After this prelude Chapter 4 considers the beginning of the real drama, the era of the World Wars, where scientific warfare was first implemented; where wars approached "totality", in the sense of a total utilization in the service of war of the societal resources made available by the incipient scientific-technological revolution; and where this "revolution" made two major, blood-soiled steps toward maturity thanks to the determined application of all scientific assets.

No simple picture emerges from history. It does not present mathematics as a diabolic undertaking inseparably bound up with war, nor does it – after the opening of the scientific-technological revolution – suggest any gullible exculpation. In order to achieve analytical understanding of the present relations between mathematics and its military sponsors and applications one has to investigate the actual phenomena of today within a theoretical framework considering mathematics both as a science, as a subject for teaching, and as a tool for applications; the functioning of the social community of mathematicians and of military structures; and that societal totality in which both are embedded. Such intricacies are confronted tentatively in Chapter 5.

Of course, the question of the influence of war on the development of mathematics – "mathematics through war or through piece?" – is only the subordinate half of the issue. For mathematicians as for anybody else, the fundamental problem is that of survival, "mathematics for war or for peace?". In principle, everybody ought to agree on this point. But what can, and what should the mathematician do? This is the topic of the closing Chapter 6, which in concrete detail attempts to derive moral imperatives and corresponding practical strategies from the preceding five analytical Chapters.

1. THE PAST

Often have we been told that the development of modern sciences and especially of modern mathematics is intimately connected with the interests of armament and war. We are even told that this involvement is the *sine qua non* of scientific progress.

If that were true, little hope would be left for the future of mathematics, of science, and of our modern technical civilization: Either continuous armament will lead us into the final catastrophe (everybody risking constantly his total capital in Monte Carlo is going to loose everything some day); or disarmament will lead to an era of stagnation. It is, however, obvious, that the 5-10 billion people of the late second and early third millennium can obtain no satisfactory life neither through the mere suppression of modern science nor through reliance on already available technology. Scientific stagnation will thus lead us into an untenable situation – better, will not allow us to free ourselves of present untenable conditions. If progress is conditioned by armament, the dilemma *war* *or stagnation and ecological catastrophe* seems inescapable and without solution.

But is the arms race really a necessary condition? Was it always the condition, as claimed in certain quarters, and not only in the Galbraithian parody *Report from Iron Mountain*[2]? Critical examination of the historical claim may help us discern better the contemporary situation and to assess the authenticity of the dilemma.

A number of historical episodes seem to support the thesis of intimate dependency.

Already in the early second millennium, the Babylonians possessed what Neugebauer (1933 and elsewhere) has labelled "siege computation" (*Belagerungsrechnung*). At closer analysis, however, siege computations are no different from other computations – they are but one of several comparable field of application of the same mathematical techniques: bricks remain bricks, and volumes of earth are not computed differently if they belong in a siege ramp and not in a temple building or are to be dug out from an irrigation canal. Babylonia offers no example of a mathematical technique inspired specifically by military requirements, nor is any military stamp to be found on the global structure and style of Babylonian mathematics.

The Greeks, too, knew that war is better waged with mathematics as part of the train. Plato's "Socrates" explains that the commander needs arithmetic and geometry for displaying his troops optimally (*Republica* 525b). Certain "armchair tacticians" (*tacticiens en chambre* – thus Aujac 1975: 163) even tried to parade their hobby as a mathematical discipline, among other things because knowledge of the isoperimetric problem is of use when you try either to impress the enemy or to hide your true force. Only familiar mathematical lore, however, was implicated – as pointed out by Geminos already in Antiquity (Fragment on the mathematical sciences, ed., trans. Aujac 1975: 114).

To be taken more seriously is the systematic development of military technology in Hellenistic Alexandria (see Gille 1980). This technology employed knowledge available from existing mechanics and elementary mathematics *and* combined it into a new, consistent branch of knowledge. Even certain parts of the Heronian corpus can be interpreted as attempts to improve actual

[2] So was, e.g., Bernal's opinion: "Science and warfare have always been most closely linked; in fact, except for a certain portion of the nineteenth century, it may fairly be claimed that the majority of significant technical and scientific advances owe their origin directly to military or naval requirements« (1939: 165).

practitioners' ways through the development of a "practical mathematics" integrated in the circle of mathematical disciplines[3].

The Islamic Middle Ages took over this complex of applied mathematics and (occasionally militarily inspired) techniques and transformed it; in this way it came to have some effect in the early Modern period.

Medieval Western Europe, on the other hand, regarded mathematics only as a subject belonging to good education and as a tool for gaining knowledge of Nature; Medieval Latin mathematics was neither influenced by nor of consequence for military techniques. First the Renaissance presents us with something similar yet immensely superior to the old Alexandrian synthesis between *technologies submitted to theoretical reflection* on one hand, and *applied mathematics* on the other.The list embraces architecture; painting and the theory of the central perspective; artillery and ballistics; cartography; book-keeping; merchants' calculation and algebra. We also find a very high appreciation of the possibilities of mathematics in every practice – at times a phantasmagoric overrating. Already Tartaglia may have overrated the practical value of his new (erroneous) mathematical ballistic theory when hiding it away for years as a "damnable exercise, destroyer of the human species, and especially of Christians in their continual wars" (*Nova scientia*, trans. Drake & Drabkin 1969: 68f). Few at least will deny today that the power of mathematics was overrated when the believers in scholarly "white magic" claimed to be able to control both Nature and angels by means of arcane numbers and symbolic geometrical figures. Our modern scepticism *vis à vis* numerology and magical geometry suggests that even the Renaissance belief in the efficiency of mathematics in other, genuine technologies should be taken with a measure of sound scepticism.

As far as the development of mathematics is concerned, however, the issue of efficiency is not decisive, if only contemporaries believed in the technical significance and productivity of mathematics. The precise *way* practical concerns influenced the development of Renaissance and Early Modern science has been discussed amply, as has *the extent* to which practical concerns did so. Nobody denies, however, that technical and social practice *did* influence the development of the sciences, including the mathematical sciences. But since warfare was certainly a major constituent of consciously planned societal practice, this implies

[3] See the introductory paragraphs of his *Metrica* and *Dioptra*. The latter introduction (chapter II) first refers to the utility of the dioptra in surveying in general, but then passes on to the specific case where part of the terrain is occupied by an enemy or inacessible for other reasons. Finally Hero points to the specific utility of the device for securing that siege towers and ladders are built sufficiently high.

II. Tartaglia, ballistics, and the responsibility of the scientist

“Through these discoveries, I was going to give rules for the art of the bombardier. ... But then one day I fell to thinking it a blameworthy thing, to be condemned – cruel and deserving of no small punishment by God – to study and improve such a damnable exercise, destroyer of the human species, and especially of Christians in their continual wars. For which reasons, O Excellent Duke, not only did I wholly put off the study of such matters and turn to other studies, but also I destroyed and burned all my calculations and writings that bore on this subject. I much regretted and blushed over the time I had spent on this, and those details that remained in my memory (against my will) I wished never to reveal in writing to anyone, either in friendship or for profit (even though it has been requested by many), because such teaching seemed to me to mean disaster and great wrong.

But now, seeing that the wolf [i.e., the Turkish Emperor Suleiman] is anxious to ravage our flock, while all our shepherds hasten to the defense, it no longer appears permissible to me at present to keep these things hidden.«

Niccolò Tartaglia, *Nova scientia*, the preface (1537), ed., trans. Drake & Drabkin 1969: 68f.

concomitant military influence on the development of the sciences, not least mathematics.

This diffuse interaction between the totality of societal practice and the network of more or less mathematically founded sciences survived the Renaissance, and still survives, and we shall not discuss it further. Restricting ourselves for the moment to the period prior to the French Revolution we can, however, point to some examples of intentionally furthered scientific – in particular mathematical – development aiming at military or quasi-military advantage.

First of all, the fifteenth century Portuguese court (the court of Henry the Navigator) took up systematic development of navigational mathematics[4]. Horst-Eckart Gross comments upon its results as follows:

> Whether Portugal’s policy of strict secrecy contributed to a lack of interaction with other European centres, affecting the development of mathematics negatively, or the narrow aspiration to care for practical needs led to exclusive concentration on urgent problems of the day and thus to neglect of broader development: In any case, the favourable conditions surrounding this first attempt at a close binding of mathematics to practice neither inspired nor made possible any remarkable impulses to the

[4] Cf. H.-E. Gross 1978: 246-48. Fuller discussions are Waters 1976 and Beaujouan 1966.

development of mathematics.[5]

Like the Portuguese maritime and colonial expansion, that of Elizabethan England built on planned and systematic collection, development and (selective[6]) diffusion of scientific knowledge – not only concerning mathematical navigation and cartography, but broadly. Mathematicians like Harriot took part in the expeditions; but so did even botanists and other scholars, and Harriot's tasks in 1585 encompassed not only surveying the coastal area of Virginia but also (and mainly) ethnographic account of the culture and language of the inhabitants (Lohne, "Harriot", p. 124; cf. Boas 1970: 191). Francis Bacon's programme for social improvement through learning was drawn up toward the end of this period and stands as a theoretical embodiment of the actual policies.

The Elizabethan encyclopedic policies and their Baconian apotheosis are reflected in the ideas behind the English Royal Society and the various Continental Royal scientific academies of the seventeenth and eighteenth centuries. Their task was to attend to the systematic production of scientific knowledge – thus serving the strength of state and economy. One of the means to this end was the announcement of prize subjects, which would often require mathematical answers to practical problems[7]. Since the strength of the state was militarily defined, and since the prizes might equal the yearly salary of a professor, the academies thus became efficient transmitters and interpreters of military needs for the mathematical sciences.

Research was also made for order. "Hooke's law" was in all probability a theoretical spin-off from empirical inquiries in the elasticity of wood, ordered by the Royal Society on behalf of a Navy wanting to cut down the consumption of wood in shipbuilding (see Merton 1970: 178f).

Finally, the training of military officers should be mentioned (a similar story could be told about naval officers and officers of the mercantile marine). Most regularly, fictional as well as technical literature of the seventeenth and eighteenth

[5] Gross 1978: 248. Already now we may point out the general importance of these observations for the discussion of contemporary military research.

[6] John Dee, the mathematician-magician who published prolificly on "occult« secrecies, kept "his treatises on navigation and navigational instruments deliberately ... in manuscript« (J. B. Easton, "Dee", p. 5).

[7] Thus, in 1727, the French Académie des Sciences asked for the most efficient arrangement of masts on a ship – a problem which the sixteen year old Euler answered though without receiving more than *accessit* (see A. P. Youschkevitch, "Euler", p. 468).

III. Robinson and mathematics

In Defoe's novel, all we are told about Robinson Crusoe's education as a seaman is that

> ... from my Friend the Captain ... I got a competent knowledge of the Mathematicks and the Rules of Navigation, learn'd how to keep an Account of the Ship's Course, take an Observation; and in short, to understand some things that were needful to be understood by a Sailor.

Explaining how he survives and manages to build up a civilization *en miniature* on his island he observes

> that as Reason is the Substance and Original of the Mathematicks, so by stating and squaring every thing by Reason, and by making the most rational Judgment of things, every Man may be in time Master of every mechanick Art. I had never handled a Tool in my Life, and yet in time by Labour, Application, and Contrivance, I found at least that I wanted nothing but I could have made it ...

Defoe, *Robinson Crusoe*, quoted from Defoe 1927: I, 18, 77

"Who learns the officer's job well learns mathematics«. And who learns the fairly simple navigational mathematics learns – according to Defoe – practically everything.

centuries mentioning military matters will point to the importance of mathematics. Who learns the officer's job well learns mathematics (thus also Defoe's Robinson, cf. Box III). But which mathematics, and for what purpose?

Two branches are important. One is fortification mathematics, the technique of optimizing the complex polygonal fortification structures of the seventeenth and eighteenth centuries under the conditions posed by the object to be protected and by available artillery (cf. Schneider 1970: 223-227). The technique was based on mathematical tables, and was taught at officers' schools, especially the French *Écoles d'artillerie*.

Another branch, taught with no lesser theoretical ambition at the artillery schools, was ballistics based on the Galilean parabola (see Charbonnier 1927: 1018-1040, and Schneider 1970: 222f). Even here, extensive mathematical tables were needed, among other things because the velocity of the projectile as a function of the quantity of gunpowder was not known, even with the assumption of uniform projectiles. Toward the end of the eighteenth century, the calculus was introduced in the curriculum in order that air resistance might be considered (on the basis, it is true, of a theory which was wrong but which led to solvable differential equations; ambitions of teachers rather than the real fulfillment of officers' needs appear to have been the vehicle bringing infinitesimal mathematics into the military curriculum).

In both branches, all sorts of geodesics and their basis in trigonometry, logarithms and instruments of analogue computing were fundamental.

2. THE IMPLICATIONS OF HISTORY

Hellenistic Antiquity did present us with an interaction between the development of mathematics and that of military technology. But was it really important, seen from the point of view of mathematics? After all, Hero's *Metrica* (or any other work of his) ranks far below the works of Eudoxos, Euclid, Archimedes, Apollonios, Ptolemy and Diophantos, both regarding importance for the development of Ancient mathematics and, especially, if we think of later scientific *and technological* influence.

A similar point holds for the Renaissance. Of those many branches of applied mathematics which evolved during the Renaissance, only algebra proved really fundamental for the over-all scientific progress of mathematics.

On the limit between the Renaissance and the Modern era (and on the limit between mathematics and mechanics) we encounter Galileo's explorations of the free fall and of the strength of materials in the *Discorsi*. While *algebra* has no relation whatsoever to military questions, Galileo's work has a over-all, but precisely *over-all*, connection to problems of physical technology; when discussing firearms he points out explicitly that his ballistic theory applies to mortars only, other weapons producing too great air resistance (*Discorsi*, 4th day, theorem 1 – trans. Crew & Salvio 1914: 256).

Our observations on the Renaissance are of general validity: The ultimate significance of an individual practical problem for the global long-run development of mathematics is random[8]. The solution to the problem may prove completely peripheral (as Hero's *Dioptra*), or it may call forward fundamental new developments (as did late Medieval merchants' algebra). Of course, all intermediate situations are also possible.

The demands of military practice to science may be direct. More often,

[8] This observation does not subtract from the global importance of total societal practice as a governing condition and source of energy for mathematics as a specific practice. This question is discussed at some depth in Chapter 5.

however, they will be indirect (cf. Galileo). In the latter case, practical challenges are no different even if they regard practices with warfare application. Moreover, even though their possession of simple names might tempt us to regard them as indivisible entities, and though any search for "influences" suggests the idea of unilinear causal chains, *science* as well as *practice* are *networks*. Looking at Galileo's *Discorsi* one will easily see that Euclid and Archimedes and the ambition to come to grips with the Medieval theory of motion were quite as important for Galileo as practical problems of fall.

The broader a certain practice in its demands to science, the greater is the probability that a broad and coherent scientific development will be called forth (e.g., the commercial calculations of the late Middle Ages and the Renaissance). The more punctual, the greater the chance that the problem (if not recurrent in new forms) will either find an isolated solution – or, if no such solution can be found, will be shelved.

Let us look at the instances of systematic sponsoring of scientific development from the fifteenth to the eighteenth century in this perspective. The Portuguese development of navigational mathematics was already characterized as punctual and hence infertile. Even in later years, cartography and navigational mathematics were *on the whole* barren with regard to further mathematical development – as the mathematics employed by Plato's commander it based itself on a level which had become elementary. Still, navigation was one of the driving forces behind the development of new computational techniques, including the invention of logarithms; eventually it thus became part of the network behind modern numerical mathematics. Navigation was also in need of reliable techniques for precise empirical determination of geographical latitude. This could only be done either through the construction of accurate chronometers or via the development of a precise theory of the lunar movement. These were focal interests in the development of theoretical mechanics in the seventeenth and eighteenth centuries, inspiring (together with other concerns) Huygens theory of the cycloidal pendulum, Newton's celestial mechanics, and the further refinements of that theoretical structure (see, e.g., Mason 1962: 270f).

Of those practical preoccupations which were communicated as prize subjects, many proved fruitful, *because of* the interpretation provided by the academies relating them to the network of actual scientific knowledge and theory.

Once more, however, the practice of war turns out to possess no privileged position: shipbuilding remains shipbuilding, as "bricks remain bricks". In the end, the internal structure of actual science came to determine what could develop – and what not: Hooke made no mathematics, and no fruitful generalization, out of the question in which season trees to be used in shipbuilding were best cut down; in the seventeenth century, this issue did not lend itself to mathematization. The sole result of his investigation to be remembered today was his “law”, the determination of the relation between load and bending, which *could* be mathematized; the fruitfulness of the law, however, only resulted when his law of proportionality was integrated into the structure of Newtonian mechanics. Precisely this circumstance illustrates the necessity of expert interpreters (the staff of the academies) translating *preoccupations* into scientifically relevant *problems*.

Officers' mathematics was, to an even higher degree than navigational mathematics (because the requirements of accuracy were higher in navigation, and because techniques were developed by cartographers and geographers before being used by the officers), “canned mathematics”. Officers' mathematics was mainly influential through being an important agent for the spread of mathematical literacy – proportionally with the general social weight of officers (which was certainly heavy). No *new* mathematical developments sprang from the officers' schools until Monge.

3. NINETEENTH-CENTURY PRELUDE

Regarding the relation between science and technical practice, as in so many other ways, the nineteenth century was opened by the French Revolution. The engineering education at the École Polytechnique announced fundamental renewal. The engineer in the contemporary sense of a scientifically trained technician hardly existed before. His predecessors in the seventeenth and eighteenth centuries were the mathematical practitioners[9], taught rather as a “higher artisans” than scientifically. At the École Polytechnique, which was founded in 1794 as a civilian institution and transferred in 1804 to the Ministry

[9] See Schneider 1970, and the fuller presentation of English “mathematical practice« in Taylor 1954 and 1966.

of War, future military engineers (who in later life would often end up as civil engineering officials) were taught fundamental science, i.e., mathematics, for two years, before specializing at other schools (cf. Klein 1926: I, 66, and Box IV).

The École Polytechnique was an institutional reflection of some of the carrying ideas of the Revolution, according to which education and science constitute the fundament of social progress – ideas rooted as well in utopian-rationalistic Enlightenment thought as in unsentimental bourgeois strategies in the struggle for societal ascendancy. In the context of the revolutionary and Napoleonic wars, which for the first time in Modern history attempted the total mobilization of societal resources, the idea of scientifically founded societal life was naturally transformed into a notion of scientifically founded warfare. One manifestation of this scientific foundation of war (and of the "militarization of reason") was the just-mentioned transfer of the École Polytechnique to the Ministry of War in 1804. It was, however, only a manifestation, a symptom of a general trend: a trend whose principles were formulated by Clausewitz[10]; which had its decisive breakthrough in nineteenth-century Prussian staff planning (which so to speak dealt with wars to come as a complex engineering tasks – see Addington 1984: 45-49); and which today is the essential element in the strategic planning of all great powers (where it may, if really applied in full consequence, lead to the acknowledgment that war can *no longer* serve politics as a tool in the nuclear age, but where conventional application of its principles – as "brinkmanship" or in other versions – may on the contrary lead directly into the ultimate holocaust).

Not only with regard to the triumphal progress of the engineers is the École Polytechnique thus a portend. In the early nineteenth century, however, time was not ripe for successful implementation of the ideas underlying the school. "The time" – that is, the structure of society; the level of productive forces and the state of the sciences. As intimated by the polytechnician Carnot in the preface to his *Réflexions sur la puissance motrice du feu* (ed. Fox 1978: 61f), England had won the war against France because of French lack of industrial capacity (whence not, we may add, for French mathematical or military deficiency).

The case Gaspard Monge is illustrative (see Wolf 1952: 59f; Loria in Cantor

[10] Diderot's *Encyclopédie raisonnée* ... had asserted that *war is unreasonable*, "a fruit of the depravation of men; it is a convulsive and violent illness in the body politic« (ed. Soboul 1976: 176). Clausewitz, who was anything but a sympathizer of the Revolution, had learned from Napoleon's strategy that *war must be waged with as much reason as possible*. This is the cardinal message of his *Vom Kriege*. In Max Weber's terminology we could speak of a shift from *Wert*- to *Zweckrationalität*.

IV. École Polytechnique: Mathematics, and nothing but

During its first decennia, the curriculum of the École Polytechnique contained nothing but mathematical and semi-mathematical subjects:

	Double lectures (1½ hours each)
Pure analysis	108
Applications of analysis to geometry	17
Mechanics	94
Descriptive geometry	153
Drawing	175
TOTAL	547

(Klein 1926: I, 66)

1908: 626ff; and Taton, “Monge”). Before the Revolution he had been a highly appreciated teacher at the artillery school of Mézière and developed there his descriptive geometry, which in that context must be regarded as an important though random spin-off from fortification mathematics, permitting that its complex arithmetical computations be replaced with elegant and rigorous geometric constructions. In the institutional and mental context of the early École Polytechnique it ripened as something very much different: One of the main subjects of teaching, which came to influence deeply future engineers and hence also a generation of future mathematicians. And yet, in the final instance nothing really new came out of the “case Monge”. The intimate interaction between mathematical fundamental research and the applications of mathematics disappeared from the École Polytechnique after ten to twenty years’ Restoration. From descriptive geometry sprang (apart from a rather isolated though indispensable auxiliary technical discipline) ultimately random even if epoch-making *pure-mathematical* spin-off: The modern theory of projective geometry, created by the polytechnician Poncelet while a Russian POW. All in all, we may conclude, an interaction between mathematical theory and societal practice of rather traditional nature.

The genuine innovations of the nineteenth century are to be found at other fronts. First of all, the preconditions for the scientific-technological revolution of the twentieth century were established: The full display of industrial capitalism and the institution and institutions of the modern State; an industry able to make use of the scientifically trained engineers, i.e., of the actual level of science of any time; *science itself* understood as the business of systematic research, attached to universities, technical highschools and other institutions of higher learning; and a maturation of mathematical, physical and chemical knowledge leading to direct industrial applicability. Prerequisites for this maturation were, in addition to an immense quantitative growth, a complete reorganization of knowledge and a far-ranging division of intellectual labour. Thus, only the early nineteenth century witnessed the birth of *physics* as one interconnected field of knowledge; during the following decades followed engineering sciences(see, e.g., Channell 1982) and the conceptual and institutional separation of *pure* and *applied* mathematics[11].

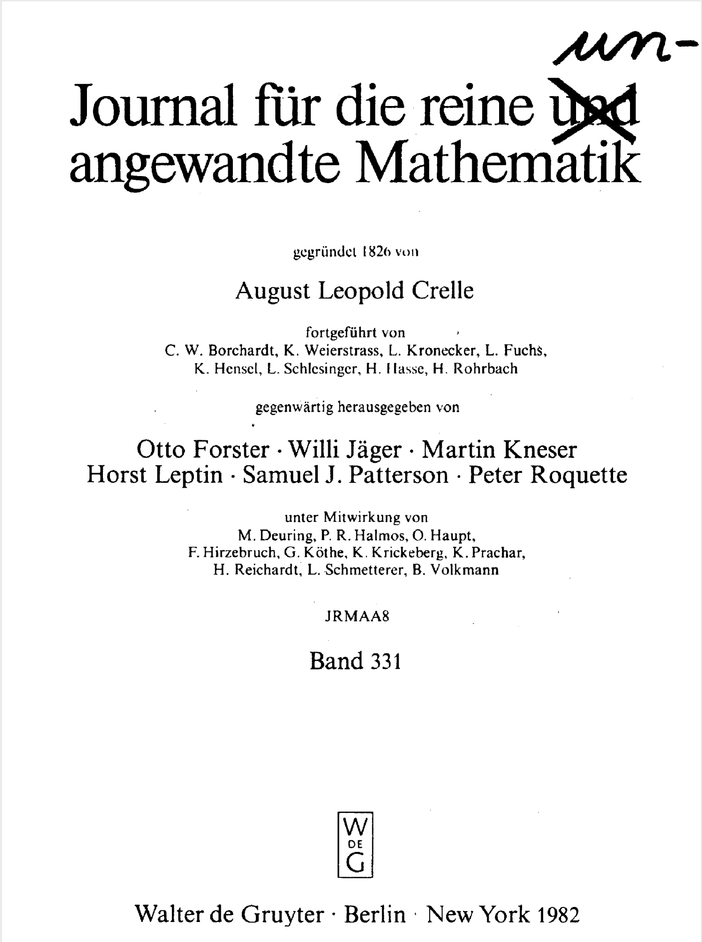
That close association between mathematical science and military practice which seemed to be inaugurated by the École Polytechnique, on the other hand, came to nothing at this first attempt. Throughout the nineteenth century, military needs only played an indirect role for the development of mathematics, mediated through industry and through the general claims on mathematics raised by industry.

4. THE ERA OF THE WORLD WARS

> "The modern war is the world war. We have known two of these. World War I was fought with old-fashioned armament – and yet it was a war of unprecedented character. It was a war involving all leading powers of the world. At stake was the worldwide distribution and redistribution of spheres of influence and the ranking order of the leading imperialist powers. It was waged at all fronts of the world. Finally, it was a total war: It was not a mere confrontation of military force in the

[11] Conceptual differentiation combined with an attempt to preserve institutional unity is reflected in the titles of the first specialized mathematical journals. The first was founded by Gergonne in 1810 and bore the name *Annales de mathématiques pures et appliquées*. In 1826 Crelle's *Journal für die reine und angewandte Mathematik* followed, and in 1836 Liouville's *Journal de mathématiques pures et appliquées*, both of which are still alive. The impossibility to maintain institutional unity was reflected in the pet name soon and deservedly given to Crelle's *Journal, viz, Journal für die reine, unangewandte Mathematik.*

V. “Pure, unapplied mathematics«



un-

Journal für die reine ~~und~~
angewandte Mathematik

gegründet 1826 von

August Leopold Crelle

fortgeführt von
C. W. Borchardt, K. Weierstrass, L. Kronecker, L. Fuchs,
K. Hensel, L. Schlesinger, H. Hasse, H. Rohrbach

gegenwärtig herausgegeben von

Otto Forster · Willi Jäger · Martin Kneser
Horst Leptin · Samuel J. Patterson · Peter Roquette

unter Mitwirkung von
M. Deuring, P. R. Halmos, O. Haupt,
F. Hirzebruch, G. Köthe, K. Krickeberg, K. Prachar,
H. Reichardt, L. Schmetterer, B. Volkmann

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Walter de Gruyter · Berlin · New York 1982

Already the first specialized mathematical journal, founded by Gergonne in 1810, had the title *Annales de mathématiques pures et appliquées*. The ideal that mathematical science was to embrace both theory development and advances in applications was later expressed in the titles of Crelle’s *Journal für die reine und angewandte Mathematik* (1826) and Liouville’s *Journal de mathématiques pures et appliquées*. Non e the less, the nineteenth century tendency toward specialization and crystallization of “pure mathematics« as a separate field was soon reflected in the practice of the journals, and Crelle’s *Journal* was rapidly given the pet name *Journal für reine, unangewandte Mathematik* (see Klein 1926: I, 95).

field, but also a trial of strength comparing the total productive capacities of the belligerent powers, in which not least the social and political cohesion of these powers was tested. The war was thus directed at the entire society of the adversary, towards his productive ability, as also against the cohesion of his society, against the reproduction of his social life, and against his whole social order” (Jarvad 1981: 6f).

In the scientific-technological revolution, and even during its early years, *science* is and was an essential constituent in the “productive capacity” of society. This was reflected in the marshalling of science in the war effort during World War I.

The scientists, though rarely fundamental science as such, were incorporated in the military machine as highest-level technical personnel. A attempt was made, more systematic than ever before, to conduct systematic technical development in large scale on the basis of the actual stance of fundamental science as mastered

VI. The sciences in World War I

"Through the summer of 1918 the German physical scientists, like the rest of the German public, continued to look forward with confidence and satisfaction to a victorious conclusion of the war in which they had been engaged four years. They, perhaps more than any other segment of the German academic world, also felt *self*-confidence and *self*-satisfaction due to their contributions to Germany's military success and to their anticipation of a postwar political and intellectual environment highly favorable to the prosperity and progress of their disciplines. ... The chemist, the physicist, the mathematician, ... emphasizing the great practical importance of their subjects during the war and the desirability and inevitability of still closer collaboration with technology in the future, looked forward to yet more, larger, and better stocked institutes and to substantially increased public esteem and academic prestige.«

(Forman 1971: 8f)

by fundamental scientists. Most important were chemistry and metallurgy, less important the physical sciences; mathematics only came into consideration as an auxiliary discipline, as "applied mathematics"[12]. (That the Engineer Corps would now as before make use of mathematics does not concern us here; as in the eighteenth century, or in Ancient Greece and Babylonia for that matter, its techniques were based on what had since long been reduced to the elementary level).

Accordingly, the anti-chauvinist G. H. Hardy could justly defend his work in the "pure" theory of numbers in his famous comment from 1915 upon the regimentation of other sciences in the war (and upon their services for industrial capitalism): "a science is said to be useful if its development tends to accentuate the existing inequalities in the distribution of wealth, or more directly promotes the destruction of human life" (auto-quotation in Hardy 1967: 120). Only some 20 years later, in the preparations for the next inferno, would his cherished analytical theory of numbers become "useful" as a secret tool for code construction and code breaking (had Hardy known about it, he might perhaps have approved reluctantly; he was no less an anti-fascist than a pacifist, and morally involved in mankind rather than in mathematics[13]).

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[12] Still, Horst-Eckart Gross observes that mathematicians "participated to a considerable extent« in the development of aerodynamics (used for the construction of airplanes), which may have "inspired the development of mathematics« (private communication). Cf. Box VII.

[13] At least in 1940, he did not suspect the potentialities of his favourite discipline – see Hardy 1967: 140. But he was no convinced opponent (nor, for sure, a determined protagonist) of the application of science in war, if war was inevitable (ibid., pp. 141f).

VII. Mathematics in World War I

Note 12 cites H.-E. Gross for the suspicion that the participation of mathematicians in the development of aerodynamics and airplanes may have inspired the postwar development of mathematics. Indications that the suspicion may be justified will be found in W. H. Young's address to the International Mathematical Congress of 1924: Mathematicians were not only, in his opinion, necessary for the further development of hydrodynamics; both "in the theory of Ballistics and in Airplane theory« important problems for theoretical mathematics still remained unsolved (and some of them remain so to this day – BB) (Young in *Proc. ... 1924*: 156).

During and immediately after the War a global change of mathematicians' attitudes to their subject can also be perceived. At the Fifth International Congress in 1912, even the results of applied mathematics were understood in the spirit of neo-humanism, as "truths about the universe in which we live« (G. H. Darwin in *Proc. ... 1912*: 35). The next Congress was summoned by French mathematicians in Strasbourg in newly reconquered Alsace, barring the "criminal« and "unworthy« German and Austrian mathematicians, who had worked for the enemy. For all his enthusiastic integration of mathematics with the French cause, Picard worried in his opening address that the young generation would concentrate on the applications of mathematics and neglect the development of pure theory in the years to come; evidently, the importance of their science in the victorious military machine impressed the youth (*Proc. ... 1920*: xxviii). In the more serene climate of the following International Congress in Toronto in 1924, H. S. Béland, Minister of Health and of Soldiers' Civil Reestablishment and representative of the Canadian Government, stigmatized the application of Science as "di[s]figurement of science's divine and celestial role [misprinted as "rule«], *viz* "the improvement of the condition of humanity, morally, intellectually, economically, and socially«. In 1924, the applications of mathematics were still understood in specific technical and not in any neo-humanistic sense (cf. Young as cited above); but there was now full confidence that mathematical fundamental research and pure mathematics were legitimate partners in the enterprise (*Proc. ... 1924*: 52, 156).

After World War I, the attempts to organize technical development on a large-scale scientific basis were given up step by step[14]. The scientific-technological revolution was still too young for society (and especially for private industry) to venture into such undertakings unless in total war[15]. Only the collaboration

[14] The gradual dismantlement applies to primarily England (see Rose and Rose 1970: 40ff) and the U.S. (see Kevles 1978: 148-154). Defeat and blockade called forth a special situation in Germany, where the break was abrupt. The *Notgemeinschaft der deutschen Wissenschaften*, founded 1920, managed to bring German fundamental science successfully through the twenties, with the intention to save scientific culture and thus preserve the basis for later technical development, but did (and aimed at) nothing more (cf. A. Hermann 1982: 116-125). Approximately the same situation seems to be reflected in the gradual expansion of grants for and positions in applied mathematics during the twenties (cf. Bernhardt 1980 and Tobies 1984).

[15] Actually, the conflict between private enterprise and publicly initiated research had made itself felt even during the war. Physicists had thus been excluded from the earliest U.S. sonar research in 1917 because their presence would complicate the patent situation, as explained by Admiral Griffin (cited in Kevles 1978: 120).

between the Nazi State and the German chemical industry for the production of substitute raw materials, the steady expansion of industrial research in the United States during the 1930es and the era of 5-year planning in the U.S.S.R. re-established the direct coupling of science to technological practice ("science as a direct productive force", as formulated in a slogan). Not until the Second World War were things to become really serious.

From the First World War it was well known that science could also be a *direct destructive force*. According to a widespread anecdote, the U.S. Minister of War had declined the services of the American Chemical Society during World War I, having discovered "that it was unnecessary as he had looked into the matter and found the War Department already had a chemist" (James B. Conant, quoted from Greenberg 1969: 88). No ministry of war desired to repeat that blunder (even though the Wehrmacht almost managed to do it in Zuse's case, cf. Box IX); researchers were therefore moved to other work in the laboratories, but not sent to the front.

The most famous scientific development project of World War II is the "Manhattan Project", the creation of the atomic bomb[16]. This was no pure development project in the style known from World War I: This time, even the leading fundamental scientists were not yet in possession of all the knowledge required from their side; hence, systematic and extensive fundamental research was required. Some 150 000 persons came to be engaged in the project; a plenitude of researchers from the most diverse disciplines took part, along with development engineers from public institutions and private industry; the budget (2 billion $) has been estimated to equal roughly the total expenses for research and development in world history until 1940.

The Manhattan Project was the largest but not the only development project involving fundamental research. So did the development of radar (begun already in the thirties), of penicillin, of the jet motor, and the realization of new levels in metallurgy, sonar technology etc. In or near the domain of mathematics special notice may be taken of new developments in hydrodynamics and the building of the first efficient American electronic computer – the ENIAC, planned initially for ballistic calculations – as well as the construction of other American computers utilizing relays; developments in electromagnetic field theory and in the theory of networks associated with the development of the radar; Zuse's German computers, some based on electron tubes and some on relays, and used among

[16] See, e.g., Jungk 1958: 112-123; Kevles 1978:324-333; Greenberg 1969: 117-125; and *A History of Technology* VI, 226-276, *passim*.

VIII. Mathematics and mathematicians in World War II

Already during World War II one Dr. Jewett, then President of the U. S. National Academy of Sciences and vice-president of the American Telephone and Telegraph, declared that “Without insinuating anything as to guilt, the chemists declare that this is a physicists’ war [while World War I was known as a ’chemists’ war’]. With about equal justice one might say it is a mathematicians’ war«. This was quoted by Marston Morse (1943: 51), creator of the modern calculus of variations and at the time a member of the advisory committee on war application of mathematics (Reid 1976: 237), in an article on “Mathematics and the Maximum Scientific Effort in Total War”.

Morse motivates this by the “machine nature of modern warfare« which not only “places engineering skill at a premium« but also, because it is “a war of invention«, calls for “a new and more mathematical use of machines«.

Often, “more mathematical uses« of technology presupposes no new mathematical research. This was also the experience of most of the mathematicians who worked for the War, as told by J. Barkley Rosser (whose intimate acquaintance with army mathematics during the Vietnam War is amply documented in *The AMRC Papers*, p. 95 and *passim*):

> I have written to practically every [U.S.] mathematician still living who did mathematics for the War effort (there are still close to two hundred) and I asked for an account of their mathematical activities during the War. Many did not answer. And many who answered said they did not really do any mathematics. I had a one-sentence answer from a man who said that he did not do a thing that was publishable. If we equate being mathematics to being publishable, then indeed very little mathematics was done for the War effort. But, without the unpublishable answers supplied by several hundred mathematicians over a period of two or three years, the War would have cost a great deal more and would have lasted appreciably longer. (Rosser 1982: 509f)

The various examples presented by Rosser demonstrate that what was needed was the – unpublishable – common sense of the trained mathematician as combined with his routine and his comprehensive perspective. In reality this is nothing but the old fortification computation and officers’ mathematics transposed into the twentieth century.

Most of what Morse discusses in his article on mathematics in total war belongs to the same *genre* or below (“swift, accurate mathematical computation« and “solution of problems of elementary algebra, plane geometry and plane trigonometry« together with fundamental mechanical physics and “good health and hard physical condition«).

The experience of the War is of general validity for the scientific-technological revolution: Full utilization of science-based technologies presupposes broad scientific “literacy«, including mathematical literacy. “The problem of navigating a plane among the islands of the Pacific is very difficult. It is possible to loose as many men by faulty navigation as through enemy fire. It is clear that we must have tens of thousands of navigators. Are our students ready for this task?« (Morse 1943: 52).

In the War, as in the scientific-technological revolution in general, this is only one aspect of the use of mathematics. The other is the integrated development of mathematical theory and application. Above and below, we discuss the development of sequential analysis and of computers. In her discussion of “The Mathematical Sciences and World War II”, Mina Rees (1980) concentrates on this aspect, the research-oriented projects. In 1943, Morse could evidently not discuss their work publicly, even though few were in a better position to know them than he.

other things for optimization of the wings of the “flying bomb”; the development of modern coding theory and the building of the British computer Colossi used for that purpose; several branches of operations research (even the very concept of mathematical research in the effective operation of military systems originated in the wake of the British radar project).

Many of these fields have proved vital in the formation of post-war mathematics (even though some of them have gained institutional and proclaimed epistemological independence). In this sense, war had a lasting influence on what was going to happen in mathematics. It can justly be asked, however, to which degree the influences really originated in the war, i.e., whether the essential break-throughs *made productive* during the war were also *created* by the war. On the whole, the answer is no. The basic mathematical ideas making possible the determination of the "inner ballistic" of the exploding atomic bomb, e.g., were taken over from the theory of the Wiener-Hopf-equation, coming thus from astrophysics, *viz* from Norbert Wiener's pre-war determination of the radiation equilibrium at the surface of a star (Wiener 1964: 142f). The key notions on stochastic processes did not spring from the branching processes of nuclear phycics; they go back to Markov's purely theoretical investigations, the results of which he had illustrated on the alternation of vowels and consonants in Pushkin's *Eugene Onegin* (A. A. Youschkevitch, "Markov", p. 129). Both Zuse and Stibitz had built their first computers before the war, and the simultaneous building of computers in Germany, Britain and the U.S. demonstrates to which extent the ideas were "in the air" (cf. Box IX)[17]. Precursors of linear programming and of the simplex method, finally, had been devised in 1938 for use in Soviet economic planning (see below, Chapter 5).

A second question is whether the war ripened the various mathematical techniques to that point where they would become influential in mathematics and in the modern civilization of computers, automation and systems planning. Once more, the answer is negative. Only when the techniques were transferred to the civilian domain and were used more variedly did they reach the point where they motivated the development of theory – and only when a fruitful interaction between theory and techniques had arisen did the latter attain their societal importance. In the earlier post-war era the rapidity with which IBM conquered the market demonstrates (as later the Japanese ascent) that only the needs of civilian business, industry and administration were broad enough to permit unfolding of computer-production and -utilization; no wonder, since only the civilian market called for and permitted mass production and continuous reduction of costs (cf. Boxes IX and X).

[17] The same simultaneity can be observed in the elaboration of ideas from mathematical statistics, leading to a similar conclusion.

IX. The first computers

The first steps toward the modern computer were taken by Stibitz in the U.S. and by Zuse in Germany.

Stibitz describes the stepwise development of his machine as follows: In his job as a “mathematical engineer« at the Bell Telephone Laboratories he worked in Autumn 1937 with electrical relays. From “curiosity« he became interested in their logical properties, and built a simple adding device on the kitchen table. Over the next three years, this led to the construction of a device (still based on relays) for the multiplication of complex numbers, which was by then becoming important in the telephone industry in filter theory and in the calculation of transmission lines. The costs (20 000 $) prevented the construction of further machines – until another one was ordered by the National Defence Research Committee for use in air defence calculations. Further models followed, but until the end of the War air defence remained their only application. (Stibitz in Metropolis et al 1980: 479-483).

Even the development of Zuse’s devices shows that time was needed for the computer to unfold its potentialities, and that this could neither be done in pre-war civil application nor in World War II: After private preparations Zuse built a binary calculator based on relays in 1936, and in 1937 got a manufacturer to take interest in his prototype (though only with great difficulty). At the beginning of the war he was not excepted from ordinary mobilization, in spite of a declaration of the above-mentioned manufacturer that his invention would be important to the Air Force. “The German aircraft is the best in the world. I don’t see what to calculate further on«, as Zuse quotes his major. Only after half a year was he transferred – not as a computer inventor but as an engineer – to the aircraft industry, which gave him the opportunity to continue work his on the computers. Even in this case, only a few machines were built, and they were applied only in a single context: Aviation computation, and process control in the aircraft and missile industry. Zuse’s very advanced theoretical ideas did not get beyond his own mind and his private notes. (Zuse in Metropolis et al 1980: 611-615).

The same observation holds for operations research, systems control etc. Only the broad and varied civilian applications changed their governing paradigm from “Portuguese navigational mathematics” to “Renaissance algebra”.

We may hence conclude:

1. Even if the military needs of World War II promoted fundamental research, only “oriented basic research” was in fact involved, which brought no essential breakthroughs. Long-term needs of science (both regarding its own development and its ability to meet long-term societal demand) were not fulfilled to any remarkable degree.

2. In the long run, military technological development receives more from civilian technology and science than it has to offer.

3. Even if the budget of the Manhattan-project be only approximately comparable to the sum of all earlier costs of research and development, we must (leaving aside the purpose of the project) characterize the scientific productivity of this Gargantuan project as outrageously low: Certainly, it did not double the

X. Univac and IBM: The costs of too intimate relations with the DoD

ERA, the Engineering Research Associates (later integrated in the Sperry Rand Corporation and known as Univac), was founded by former reserve officers with a wartime background in cryptographic computing. For a long time the firm worked exclusively for the military on classified tasks. According to a representative of the firm, the cost was: Orientation toward the solution of already defined isolated problems and not toward the investigation and analysis of complex situations; lack of experience with creative interaction between users and manufacturers; and thus eventually delay of “its entry into commercial activities« and delay of “its maturation into a total computer systems supplier«. The description is confirmed by the events from 1953 onwards. At that time IBM offered its first “general purpose computer«, the 701. ERA was now also oriented toward the civilian market, and a few months later it offered a technically comparable machine, the 1103, and gained certain initial advantages thanks to its longer experience with electronic computing; very soon, however, IBM took over the dominant position (Tomash in Metropolis et al 1980: 485-490; cf. also Goldstine 1972: 325-329).

Even the IBM 701 was originally conceived as a “defence calculator«, and the first customer machine went to the nuclear Los Alamos Laboratory. From the beginning, however, it was planned deliberately to possess all-round applicability – in agreement with the customs of IBM, which for decennia had produced office machines and had well-rooted traditions for employment of broadly qualified scientists and for interaction with the university environment (Hurd in Metropolis et al 1980: 390-392; cf. Goldstine 1972: 329-332).

knowledge and technical ability of Mankind!

4. On a planet governed by human reason (and not merely through Clausewitzian strategic rationality), the direct passage “from *Eugene Onegin*” to industrial application of Markov processes would have been possible, bypassing the scandalous squandering of resources in the Manhattan project. Only in a militarized world (if at all) is militarism a precondition for scientific progress.

5. OUR PRESENT SITUATION

“Only in a militarized world (if at all) is militarism a precondition for scientific progress”. Very nice. But what is the relevance of this seemingly comforting dictum for *our* world?

Let us start with the mathematicians’ point of view, as expressed in their conception of mathematical excellency. The mathematical analogue of the Nobel

Prize, the Fields Medal, is awarded every four years to two to four young mathematicians for epoch-making research. The selection of laureates since the first award in 1936 and the eulogies delivered by leading mathematicians show what is considered epoch-making by mathematicians. Deemed worth reward were only

- the solution of old *mathematical* problems,
- the unification of several *mathematical* fields through the discovery of transverse connections and new conceptualizations, and
- the opening of ways to new *internal developments* in mathematics.

These criteria hold even in those two to four cases where the laureate has worked in fields somehow connected to applications (cf. Box XI).

If applications are important to the development of mathematics, then at least not so important that their influence cannot be suppressed from the consciousness of even the brightest mathematicians. Influences from societal practice on the development of their field must hence, in so far as they exist, mainly be of an indirect nature.

They *do* exist, and the outlook of the “leading mathematicians” is thus distorted and narrow and only a reflection of one aspect of reality: This becomes obvious, e.g., if we consider the example of nonlinear analysis. M. S. Berger’s *Nonlinearity and Functional analysis*, which can be regarded as the modern standard textbook of the discipline, lists not only extradisciplinary yet intra-mathematical sources in differential geometry and variational calculus but also in considerable detail an abundance of sources for the central problems of the discipline in classical and modern physics, in economy and in biology (Berger 1977: 10-18, 60-63).

Precisely in the domain of non-linear analysis, it is true, are strong influences from modern applications to be expected. Nonlinearity is (together with mathematical statistics) so to speak *the* mathematics of the scientific-technological revolution. Classical mechanics and classical mathematical economics build largely on linear approximations to reality without bothering about determining the higher-order deviations from linearity (cf. Hooke’s law, d’Alembert’s wave equation, and Walras’ “pure political economy”); similarly, they build on the fiction of exact and complete predictability. Application of such theories in practice then presupposes the *ad-hoc* rules of thumb of the practician knowing *when* and *how* to apply them *and when not*. If instead, as characteristic of the scientific-technological revolution, the breach between idealizing classical theory and real material or social practice is to be bridged systematically and scientifically, mathematization of non-linear relations and of the incompleteness

XI. The Fields Medal

From the *première* in 1936 until 1985, 30 Fields medals were awarded:

1936	L. V. Ahlfors	Quasiconformal mappings, Riemann surfaces
	J. Douglas	Plateau problem of variational calculus
1950	A. Selberg	Analytic number theory
	L. Schwartz	Theory of distributions
1954	K. Kodaira	Harmonic forms on complex manifolds
	J.-P. Serre	Homotopy theory of spheres
1958	K. F. Roth	Algebraic and analytical theory of numbers
	R. Thom	Topology of differentiable manifolds
1962	L. Hörmander	Linear differential operators
	J. W. Milnor	Differential topology
1966	M. F. Atiyah	Topological methods in analysis
	P. Cohen	Logic and set theoretical foundations of mathematics
	A.Grothendieck	Algebraic geometry
	S. Smale	Differential topology
1970	A. Baker	Theory of transcendental numbers
	H. Hironaka	Resolution of singularities in algebraic geometry
	S. Novikov	Geometric and algebraic topology
	J. Thompson	Simple finite groups
1974	E. Bombieri	Theory of numbers, real and complex analysis
	D. Mumford	Algebraic geometry
1978	P. Deligne	Algebraic geometry
	Ch. Fefferman	Convergence of Fourier series and Fourier integrals
	G. A. Margulis	Discrete subgroups of Lie groups
	D. G. Quillen	Geometric and topological methods in algebra
1982	A. Connes	Topology of operator algebras
	W. P. Thurston	Topological analysis of three-manifolds
	Sh.-T. Yau	Analytical methods in geometry (and *vice versa*)
1986	S. K. Donaldson	Topological analysis of four-manifolds and math. physics
	M. H. Freedman	Topological analysis of four-manifolds
	G. Faltings	Arithmetic algebraic geometry

Of these, Laurent Schwartz built his works directly on mathematical problems belonging with various applications. His theory of distributions provided a mathematical basis for apparently paradoxical

continued

methods used currently in quantum physics and in electrical engineering and physics. Donaldson had applied techniques borrowed from mathematical physics and has also worked on the theory of magnetic monopoles. Hörmander's and Fefferman's works belong in fields which originated in classical "applied mathematics«; their actual accomplishments, however, have very little to do with practical calculation, a fact which was emphasized in the eulogies. So in Hörmander's case: "Questions of this nature have no physical background but a very solid motivation: mathematical curiosity« (*Proc. ... 1962:* XLV). Fefferman's work belongs in the domain of classical analysis, which in the 40'es and 50'es was considered closed and hence "dead«. He got the Medal for the "unification of methods from harmonic analysis, complex variables and differential equations«; the realization that "in many problems complications cannot be avoided« (*Proc. ... 1978:* 53) was praised.

Atiyah's eulogy of Donaldson (*Proc. ... 1986:* 3-6) mentions and praises the mutual fertilization of pure mathematics and theoretical physics. That, however, is quite exceptional. Even when we go to Laurent Schwartz, whose achievement is so obviously connected to non-mathematical practice, this is no theme for Harald Bohr. Instead, his ability "to shape the new ideas in their purity and generality« is underscored ("the physicists and the technicians« *are* mentioned, it is true, but only so that it may be told that their methods are illegitimate). (*Proc. ... 1950:* 130-133, quotations pp. 133 and 130). In all other cases, extra-mathematical connections have been mediated historically through multiple conceptual and disciplinary reconstructions. None the less, the results of several Medal-winners have stirred interest in other sciences (so Thom's in biology, Atiyah's in quantum dynamics, Smale's in economics). The inner dynamic and the dominance of internal interactions does not impede the applicability of mathematics; on the contrary, the existence of a dynamic inner structure is one (*of several!*) conditions that qualitatively *new* applications may turn up.

Connections between Fields Medal winners and the military cannot be traced at the level of mathematical substance but only at the level of NATO- and similar grants.

(Sources: *Proc. ... 1936 - Proc. ... 1986*; *Notices of the American Mathematical Society* **29** (1982), 499-502; Albers et al 1987)

of information must be appealed to.

If instead we look at disciplines like modern topology or modern algebra, such direct inspiration from problems of practice is not to be expected, nor to be found. In another sense, however, even these disciplines can be regarded as characteristic of the scientific-technological revolution. They do not mathematize the complexity of the real world but *complexity as such*[18]. In which time if not in ours would research deal with groups with 808 017 424 794 512 875 886 459 904 961 710 757 005 754 368 000 000 000 ($=2^{46}\cdot3^{20}\cdot5^{9}\cdot7^{6}\cdot11^{2}\cdot13^{3}\cdot17\cdot19\cdot23\cdot29\cdot31\cdot$

[18] This is no mere speculation by analogy, but corresponds to formulated mathematical ideals. Cf. the eulogy praising Fefferman for having shown that "in many problems complications cannot be avoided«.

41·47·59·71) elements[19]? Which century but the present would come to consider the infinitely irregular Mandelbrot set and no longer the supremely regular circle the most beautiful of geometrical figures?

Already non-linear analysis is thus subject quite as much to influence from the characteristics of societal practice as a whole as from specific problems. In the cases of topology and algebra, the same assertion can be made with greater emphasis.

Will all this – Fields Medal, nonlinearity, topology – go together in a common picture of the relations between mathematics, over-all societal practice and, not to forget, military influence? It will, *viz* under the heading "organized segmentation" (we could also speak metaphorically of a "division of labour").

We must remember that the number of mathematicians as well as the number of people applying mathematics is greater today than ever before. As D. J. de Solla Price once observed, the majority of scientists and engineers ever born are still alive. So many mathematicians and so many technologists are active today that strong *inner* interactions are possible and may dominate in both domains. Both domains have also developed so far beyond the terrain of common sense that most questions posed by a mathematician can only be understood (let alone answered) by other mathematicians, and that most of his works will only be directed to disciplinary colleagues (in a narrow sense). *Mutatis mutandis*, the situation of the technologist should be described in similar terms. In general, only the accumulated result of the work of many mathematicians and the airplane on which many technologists have cooperated are of any use to outsiders. Mathematics, technology, and even their single subdisciplines, are "open systems": For each average element (mathematician or theorem, engineer or machine component), interactions with other similar elements dominate in number as well as importance. For each system, these internal bonds generate both the inertia of the system and its ability to "produce" efficiently. External interactions are marginal compared to the internal ones; as in a biological system they can, however, be said to provide the necessary energy; as the pilot on the ship they may determine the direction taken by the inertial mass and thus also ultimately the character of the production.

[19] Cf. Conway 1980. Actually, the way from the group theory of the nineteenth century, which aimed at simplification of the seemingly complex and irregular, to the modern "monsters« has passed, *inter alia*, over the irreducible groups of quantum physics. Even in the case of algebra, real complexities and not only the cultural problem of complexity have played a role for the orientation of research.

These metaphors borrowed from systems theory can be filled out. The Fields Medal reflects the primary dominance of the inner dynamics. Even in the rare cases where an impact of system-external factors can be tracked, the inward-pointing aspect of the work alone is rewarded. The role of the marginal external factors, on the other hand, is obvious when we turn to nonlinear analysis. This discipline is certainly not a mere heap of mathematical answers to discipline-external problems; most theorems relate to problems actualized or created by other theorems – which is the reason that we can at all speak of "a discipline". The fundamental issue, on the other hand, and the overall aims pursued belong outside the domain and for a considerable part even outside mathematics[20]. In this way, system-external influences thus provide both energy and direction. The same could be said of mathematical statistics and probability theory.

Disciplines like topology are better shielded from extra-mathematical influences. The external sources of topology belong almost exclusively in other branches of pure mathematics: Theory of numbers, algebra, complex analysis, partial differential equations, differential geometry, and finally of course the very abstract character of contemporary mathematics in general and its interest in complexity as such[21].

Already in Galileo's time, we remember, both science and technical practice had to be understood as networks; the differentiation between physics and engineering science and between pure and applied mathematics, furthermore, were among the preconditions for the nineteenth-century beginning of scientific technology. Then, however, it is scarcely a miracle that comparable features characterize the situation in the ripening scientific-technological revolution even more clearly. The epistemological arguments that "organized segmentation" is necessary for the productivity of the total scientific-technological system are thus supported by historical continuity.

It should be observed already in this place that organized segmentation not only is responsible for the productivity of the system (which is after all a very abstract concept as long as we do not discuss *what* is being produced) but also for the distorting trends, i.e., for the insensate and unscrupulous destruction of nature and fellow beings. Each participant tends to know only his own subsystem and its inner (social and cognitive)

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[20] At the same time we observe that "real-world problems« only become productive when mediated adequately, through mathematized sciences or through other mathematical disciplines. On the level of systems theory abstractions, the function of these intermediaries is analogous to that of seventeenth- to eighteenth-century scientific academies.

[21] As with any rash generalization, prominent exceptions can be found: Catastrophe theory, and the qualitative theory of turbulence.

structure. Its outward interactions, its role in the greater whole, tend to be obscured, as demonstrated with astonishing clarity in the case of the Fields Medal. The professional conscience of the single ("naive") participant is only related to the subsystem, and the ignorance of its more global role will easily express itself as unscrupulousness with the regard to global end effects. From the overall viewpoint, "naive" participants are *elements*, comparable to the elements of an engine, and not carriers of moral responsibility.

If only the "naive" participants were present, segmentation would not be "organized"; the effectivity of each subsystem would then be measured by arbitrary local, inertial standards, and the total system would soon not work efficiently at all. But subsystems, as we have seen, are not as isolated as they seem from the perspective of local participants. Interaction between subsystems, however, is often governed by blind or halfblind economic forces, by political decisions funding one area or type of activity and not the other, or by intentional canalization of scientific information (calculated by those in power in big business or in bureaucratic or military structures) in select directions and forms[22]. In as far as this is actually the case, the standard according to which the total system is "efficient" will be determined accordingly. As long as the conglomerate of big business and bureaucratic and political power is not humanly and ecologically responsible, neither will a scientific-technological system dominated by "naive" participants" be.

Until this point, the present Chapter has only considered the links between mathematics and over-all technical and even societal practice. What is to be said about the connection to the military sector, which is after all our theme? What is predicted by historical continuity?

Never in history was there anything *specific* in war and armament, seen from the point of view of mathematics. *War* was, as one of the constituents of global societal practice, comparable to other constituents. When war could boast of societal priority, it would also be a major external influence on the way mathematics was made (cf. the École Polytechnique or the preface to the *Dioptra*). Rarely, if ever, was the influence of war and warfare of specifically military character. Hooke's law would have looked no different if the Royal Society had wanted to make economies in the construction of merchant vessels; if anybody had been willing to pay for an investigation of air resistance to sugar balls, the same questions would have been posed to mathematics as in military ballistics[23].

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[22] This latter assertion may sound overly Machiavellistic – but see the description of the "Mathematics Research Center, U.S. Army« in note 41 andd appurtenant text.

[23] Below we shall discuss various negative consequences of military influences on scientific development, summed up in the concepts of "overloading« and "punctualization«. They are not conspicuous in mathematics proper – mostly because no mathematics is produced if they are too strong. One example of this was discussed above: Portuguese navigational

Is the situation different today? Let us look at the case of sequential analysis, as it was developed in World War II. Evidently, the statistical analysis of the reliability of a production line was important in the mass production of weapons and munitions. As it appears, moreover, it had never been important enough in pre-war civil production for anybody to develop the technique. In real history *war* was thus the precondition for the formulation of the problem as a scientific question and for its solution – as once the English Royal Navy for the study of wood. Today, however, the standard examples in the textbooks deal with quality control in civilian production and other harmless – perhaps even useful – random samplings. In epistemological principle, these might just as well have presented the occasion for Abraham Wald to open up the field of statistical decision theory. The practical elaboration of the technique[24] was taken care of by members of "what surely must be the most extraordinary group of statisticians ever organized, taking into account both number and quality"[25]. At least until 1941, we have to conclude, civilian life had not matured to a point where it could organize a comparable group[26].

The possibility of a civilian development of sequential analysis is an unhistorical speculation, though supported by the detailed course of its history[27]. In *real* history, however, another mathematical technique promoted by war was developed independently in the civilian domain. As touched upon above, the first beginning of linear programming, created by T. C. Koopmans for the optimization of transport in the Pacific war, was presented in a no less developed form by L. V. Kantorovich in his Russian *Mathematical Methods of Organizing and*

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research. (Cf., however, note 35).

[24] Continuing, once again, pre-war ideas – see Wallis 1980: 326.

[25] The "Statistical Research Group« (Columbia, 1942-1945). The description was formulated by its head, W. Allen Wallis (1980: 322). According to Wallis, the group was not only unprecedented: Even afterwards, this "model ... of an efficient statistical research group« has not been equaled.

[26] Anticipating later discussions we may consequently observe that as a *socially concrete* practice war *is* something specific: When not submitted to the extreme pressure of total war, capitalist society is (or was at least until 1945) not able to launch this sort of rational organization, and hence not to make full and well-considered use of the potentialities of science.

[27] According to Wallis (1980: 326, quoting his own private report from 1950), he first got Wald interested (and that only with difficulty) in the problem of sequential tests by arguments referring to the intrinsic mathematical interest of the problem and not at all linked to the war.

Planning Production in 1939 (see Rees 1980: 618), related to the Soviet five-year planning.

During the post-war period, the *not specifically military* character of the military influence on scientific and technological development has been highlighted by the genesis of higher programming languages. COBOL (COmmon Business Oriented Language), until today the language most widely used for administrative data processing (whence most widely used *at all*), was hatched by a commission organized by the Pentagon, in which the Air Force and the Navy cooperated with representatives of the largest industrial corporations (see Sammett 1969: 330ff, and Box XIII). The language also owed its rapid spread to military initiative, *viz,* to a Pentagon declaration to buy in future only computers equipped with a COBOL compiler or with demonstrably equivalent facilities[28]. The military customer carried such weight that all manufacturers had to offer COBOL.

FORTRAN (FORmula TRANslating system), still most widely used for scientific and technical calculations, conveys the same message in other terms. The language appears to have been developed by IBM on its own initiative from 1954 onwards. The undertaking was closely bound up with the attempt of the office machine giant IBM to enter the market of scientific-technical computation and rapid electronic computers. All institutional and personal connections indicate, however, that this market was largely identical with the fraternal association of military establishment with military and nuclear technology: University of California, Radiation Laboratory; United Aircraft Corporation; Joint Meteorological Committee of the Joint Chiefs of Staffs; Oak Ridge National Laboratory; and U.S. Navy (see Goldstine 1972: 328-331, and Sammett 1969: 143).

In more recent times, finally, the Pentagon is known to have undertaken at huge costs the NATO-wide development of the programming language Ada, intended for real-time control and command of subsystems. Just as COBOL can be applied to many other administrative tasks than the management of spare parts of military airplanes; and as FORTRAN was only "by chance" developed for military and not for civilian weather forecast; so real-time communication between subsystems equipped with disparate software is not a requirement of the NATO-integration alone but a characteristic need of any large system in the present phase of the scientific-technological revolution.

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[28] H. B. Hansen, private communication. See also S. Rosen 1967: 13, who ascribes the declaration unspecifically to the "United States government«. In practice, *equivalence* could only be demonstrated if the language *was* COBOL.

XIII. Who needs COBOL?

The Pentagon-initiated commission which in 1959 decided to develop COBOL (and did it) was composed of representatives of these institutions and firms:

Air Material Command, United States Air Force
National Bureau of Standards, U. S. Department of Commerce
Burroughs Corporation
David Taylor Model Basin, Bureau of Ships, U.S. Navy
Electronic Data Processing Division, Minneapolis-Honeywell Regulator Company
International Business Machines Corporation
Radio Corporation of America
Sylvania Electric Products, Inc.
Univac Division of Sperry-Rand Corporation

That is, Air Force, Navy, Bureau of Standards, and 6 computer manufacturers. In the further work of the “Maintenance Group«, the following manufacturing and user corporations were also represented:

Allstate Insurance Company
Bendix Corporation, Corporation Division
Control Data Corporation
Dupont Corporation
General Electric Company
General Motors Corporation
Lockheed Aircraft Corporation
National Cash Register Company
Philco Corporation
Standard Oil Company (N.J.)
United States Steel Corporation

(Rosen 1967: 121f)

Ada may be overloaded for civilian purposes in its actual execution. That it is so is claimed by many experts. The integration of all arms systems during the one decisive hour of a third world war is, indeed, qualitatively different from the lasting integration within a great corporation or a national economy. The possible overloading of Ada is hence a parallel to the exorbitant reliability standards for military electronics, which Joachim Wernicke has characterized as a “tribute to an absurd understanding of technology” (the abundance of components e.g. in a modern tank being so great that it will only run c. 200 km between two thorough servicings in spite of the extreme standards for single components)[29]. However, what we might designate the “civilian-progressive

[29] Wernicke 1982: 9. As an electronics engineer and a former military researcher (now technical advisor of the West German *Grünen*) Wernicke knows better than most what he speaks about.

aspect" of Ada – that civilian utility which purchasers of the language as a commercial product expect to find – is only affected negatively by the overloading. A civilian-progressive version of Ada free from much of the overloading might just as well have been called forth directly by civilian needs.

Ada demonstrates once more that the direct passage "from *Eugen Onegin* to industrial application" is only impossible in a world militarized to a point where nation-wide scientific development projects are organized solely under the aegis of the armed forces. Confronting the apologies insisting upon the progressive role of military research with the conceivable overloading of the language also makes the general question crystallize whether the detour over military research is *a risky and murderous but all in all economically sound* or even efficient way to civilian progress, or it is, like the Manhattan Project, in addition to risk and moral monstrosity, also a waste of resources and perhaps a source of generally perverted technology?

If we compare the resources put at the disposal of military research since 1945 with the score of known gains for civilian life the term "waste" seems appropriate and even mild. The above discussion of the spin-off-effects of World-War-II-research points in the same direction. So do also theoretical arguments:

Firstly, military research is bound to secrecy. This obstructs the "natural" growth process of science, where every open question and every important result is in principle presented to the world-wide community of colleagues for criticism and further work. Vital information concerning military research circulates in narrow circuits only, not even defined by national borders but by the single institution or even working group: Portuguese navigational science is still a valid

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There is one important difference between military electronics and the super-language. While the overloading of a tank or a fighter-bomber is at least to some extent balanced by the extreme standards for single components, there are good reasons to believe that the global complexity of Ada and the necessary interconnectedness of single procedures will make even the single "elements« of the working language less reliable than normally. In civil application, this will be unpleasant and generate ineffectiveness; in the military domain things grow worse: "in applications where reliability is critical, i.e., nuclear power stations, cruise missiles, early warning systems, anti-ballistic missile defense systems« nobody will be able to intervene when things have gone astray because of "an unreliable programming language generating unreliable programs«. "The next rocket to go astray as a result of a programming language error may not be an exploratory space rocket on a harmless trip to Venus: It may be a nuclear warhead exploding over one of our own cities«, as C. A. R. Hoare warned the community of American Computer Scientists in his Turing Award Lecture (1981: 83).

Cf. also note 35 concerning the specific question of overloaded computer software.

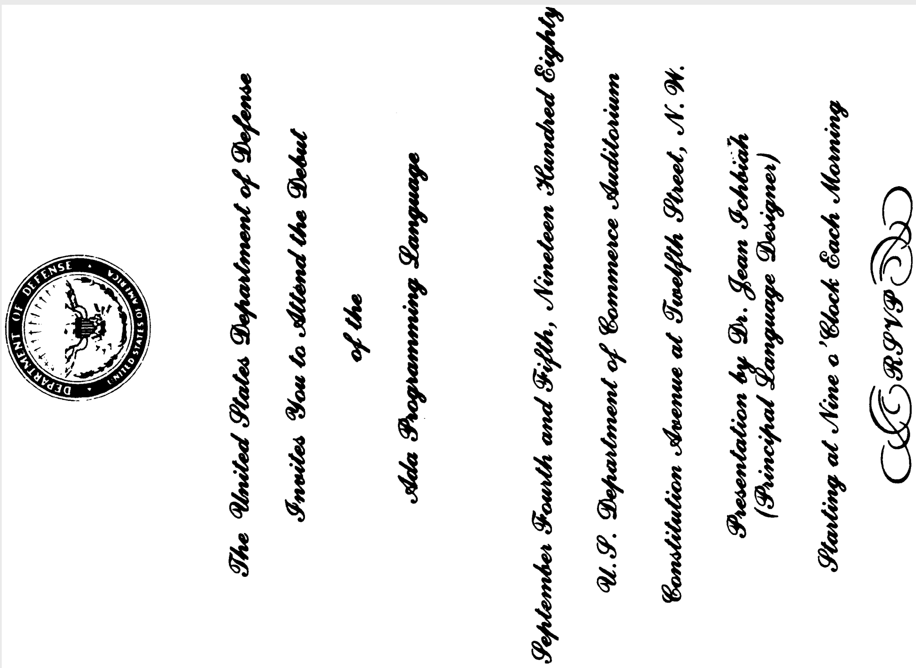
XIV. ADA

“... no great computer corporation and no group of scientists with university background sponsored Ada. The U.S. Department of Defense (DoD) set fire to the rocket, which according to the intent and the firm conviction of its creators will ascend the heaven of programming languages like a comet. In the beginning of the seventies the investigations of the DoD ascertained that the production, maintenance and use of all its different software products absorbed astronomical sums. For 1973 alone this chapter in the budget was calculated to amount to 3000 000 000 $. It was believed that the reason for this horrifying consumption was the abundance of different programming languages in use. From then on everything went on in military style« (Barth 1982: 141).

As a matter of fact, the military requirements were directed not only at rationalization and standardization of “the abundance of different programming languages in use« but also at qualitatively new performances, as described, e.g., in the foreword to *Military Standard 1815*, the official description of the language (from December 1980; reprinted in Horowitz 1983):

> ... the real-time programming language Ada [is] designed in accordance with the United States Department of Defense requirements for use in embedded systems. Such applications typically involve real-time constraints, fail-safe execution, control of non-standard input-output devices and management of concurrent activities. Ada is intended as a common high order programming language and has the mechanisms for distributing large libraries of applications programs, packages, utilities and software development and maintenance tools. Machine and operating system independence is therefore emphasized throughout its design.
>
> The Ada Language is the result of a multinational industry, academic and government effort to design a common high order language for programming embedded computer and real-time defense systems. ...
>
> (quoted from Horowitz 1983: 419)

Obviously an invitation to overload!
The computerization of the NATO-integration dressed up as a beautiful young upper-class girl. From *The Mathematical Intelligencer* **2** (1979-80), 161



paradigm; we may also think of the development of nuclear plants, where the use of the reactors for the manufacture of bombs caused "the earliest development to take place in strict secrecy, whereby the responsible engineers and physicians and the technologies which they created were shielded from the critical scrutiny of the vast majority of their colleagues". Thus according to Burhop (1980: 2), who considers this original sin against the norms of science to be an essential source for the problems which still ride nuclear technology. (Cf. also Box X on IBM and Univac).

Next, problems posed by the military are mostly of punctual character and to answer within a brief delay. "Better to have a fairly satisfactory answer now than to wait two years for one which is theoretically worked out" (the Portuguese paradigm once more!). Especially after the early sixties, where a Pentagon-conducted evaluation project "Hindsight" found very little gain for the armed forces in the entire bulk of post-war fundamental research (see Box XV), the trend has been for military development projects to build increasingly on existing fundamental knowledge alone[30].

For both reasons, resources given to military research tend to produce "less knowledge per dollar" than resources used in open civilian or fundamental research. Science *as a body of knowledge* is thus less influenced by its military involvement than might be expected from the weight of military financing. Since, moreover, not all knowledge produced for its destructive relevance is equally valuable for constructive purposes, "less knowledge per dollar" becomes *even less civilly productive knowledge per dollar*.

Some critical observers of the military economy go further, claiming that *no*, or almost no, civilly productive knowledge derives from contemporary military research. Thus Mary Kaldor (1982), according to whom military technology is since the late fifties so specialized and the "autistic drive" of the military-industrial complex so precisely focused on this specialization that spin-off from the "baroque arsenal" can only lead to total technological degeneration[31]. The American Marxist Victor Perlo (1974: 172) argues on similar lines, while the

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[30] The SDI project is often cited as an exception to this rule, or even as a portend of new trends. Firstly, however, it should be asked whether this luxurious red herring is more than a wriggle on the curve – giving exorbitant power to ignorant zealots surrounded by ill-willed advisors may break any institutional rationality for some time. Secondly, the proclamations of those enjoying the profits function as publicity and may hide more than they reveal; their truth value will only be known years ahead. Cf. *Scientific American* **255**:5 (November 1986), 54-56 (European pagination), "SDI Boom – or Bust?".

[31] Cf. also Wernicke 1982 as cited above, see note 29.

XV. Project Hindsight

In 1963, the Pentagon had the technology of 20 essential and advanced weapons analysed: Various nuclear warheads, rockets, radar equipment, a navigation satellite and a naval mine. As far as possible the contributions of separate scientific and technological advances made since 1945 to each weapon were traced. In this way, 556 separate contributions were found. “Of these, 92 per cent came under the heading of technology; the remaining 8 per cent were virtually all in the category of applied research, except for *two*«, which came from basic research. (Greenberg 1969: 59).

The methodology of the project was not without problems. Thus, all semiconductor technology was reckoned as *one* contribution (the transistor). Still, the overall result is not subject to doubt: Technological innovation takes most of its nourishment from the technology-subsystem.

Soviet economist Viktor Kudrov (1981) as well as West German and Japanese competitors of the American corporations fear that the armament expenditures may after all contribute to stabilization of the technological leadership of the United States.

Competitors have good reasons not to assess the potentialities of their rivals wrongly. We may therefore trust them so far that “less knowledge” remains *knowledge*. Kaldor’s arguments, on the other hand, are valid for many if not for all domains of armament technology – from which follows that “less knowledge” remains *less*.

Military attachment, it is true, is not the only source for secrecy, needless duplication, inadequate orientation and punctualization. Even the economic competition in capitalism[32] as well as the publish-or-perish degeneration of the scientific community itself produce such malfunctions.

Against these effects of economic forces and social structures, however, other forces are at work: Public registers of patents, the social norms of scientific life, citizens’ protest movements against baroque technology, and even the interest of the great corporations themselves in appropriate commercial exchange of knowledge. In military research, these forces are largely thwarted[33] – see Box XVI on Reagan’s “Executive Order on Classification of National Security Information”, classifying in principle all research results which have not been explicitly declassified, and on the resistance from both industry and scientists.

[32] Especially that of contemporary monopolistic capitalism, where the weapon is (real or fake) product development and cost reduction and not price reduction. Cf. note 39.

[33] For one ugly example among many, see R. J. Smith 1982, on the involvement of scientific experts in the cover-up of the atomic test fall-down in Utah in 1953.

XVI. NO ADMITTANCE! SCIENTIFIC ZONE!

Like many others, changing U.S. Governments have classified certain scientific results as important for national security, yet from Eisenhower through Nixon and Carter less and less so. Since 1980, the trend has changed violently. Already in Carter's last year, the National Security Agency, the National Science Foundation and the American Council of Education initiated a commission work which should prepare a pre-censorship on all publications in the domain of cryptology. In April 1982, this resulted in an invitation to the members of the American Mathematical Society (loyally communicated by the Society) to accept until further notice a voluntary preview – "We would welcome the opportunity to review and comment on papers, manuscripts or related items of any individual who is performing research in or related to the field of cryptology and believes such research may have national security implications« (*Notices of the American mathematical Society* **29**:4 (1982), 322f).

In the same month, the Reagan administration issued its "Executive Order of National Security Information«, which makes the classification of all scientific, technological and economic information possible if the government considers it to touch national security. In principle, all scientific information is classified unless otherwise decided.

In the final version, it is true, the major but not clearly delimited part of basic research is exempted from compulsory preview; still, administrative praxis shows that a very wide concept of "security interests« prevails. Thus, in February 1980 the organizers of an international conference on bubble memory were threatened by fines of 10 000 $, 10 years in prison, and an additional fine of five times the value of any equipment seen or demonstrated if participants from socialist countries were not disinvited (which they were).

In 1982, the deputy director of the CIA told the American Association for the Advancement of Science how global classification should be organized: By including "in the peer review process (prior to the start of research and prior to publication) the question of potential harm to the nation« (quoted in Gerjuoy 1982: 34).

The new mania for secrecy will not only damage American science, American economy and American democracy in general; it will also hamper the development efforts of the American armaments industry. This was the conclusion at which arrived a panel appointed by the National Academy of Sciences, the National Academy of Engineering and the Institute of Medicine, consisting of senior members of university faculties and administrations, former Federal officials and executives of high-technology companies, and supported by the Department of Defense, the American Association for the Advancement of Science, the American Chemical Society, the American Geophysical Union and a consortium of private foundations (see *Scientific American* **247**:6 (December 1982), 65f, "Secrecy v. Security"). This and similar advice forced the DoD to reach a certain accommodation with the opponents of secrecy; at the same time, however, other agencies continued the old policies (see *Scientific American* **251**:6 (December 1984), 60f, "Secret Struggle").

All this holds true for every kind of research associated with military development: All sciences, and not only mathematics, are frustrated by a military attachment. But it *also* holds true of mathematics. In addition, at least punctualization may affect mathematics even more than other sciences. Questions asked by technological practice to (e.g.) physics will often presuppose a inclusive understanding of the physical phenomenon concerned; this applies to the connection between the front of computer technology and solid state physics, as well as the relation of fusion reactors to plasma physics and that of meteorology to hydrology. On the other hand, military as well as most other practical claims on mathematics will ordinarily be mediated through technical problems involving mathematics as an auxiliary discipline answering isolated questions. Here “mathematics no longer appears as the ’Queen of Sciences’, but takes over the function of an ancillary science for other disciplines or for application in daily life”[34]. The function of ancillary disciplines, however, is essentially that of offering ready-made answers on punctual questions; services rendered in this capacity by mathematics (or by any other science in a similar position) are not likely to stimulate or to participate in the internal development of the field[35].

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[34] H. Werner (1982: 67), in the President’s Speech to the Deutsche Mathematikervereinigung.

[35] Obviously, this line of argument concerns “mathematics proper«. In the less “proper« but from a global perspective no less important field of *computer software*, the need for an “inclusive understanding« is as great as if physical phenonema are concerned, and a practical problem may find no solution before a fundamental breakthrough has taken place. The creation of COBOL and FORTRAN (and thus, we might claim, of “software« as a separate concern) can be quoted as examples – especially COBOL is striking because the COBOL Committee set out to find short-time solutions based on the existing state of the art and found out that only the creation of a new language would do (see S. Rosen 1967: 12f).

In later years, there seems to be a tendency that military influence has indeed not only called forth specific broad developments but even permeated the global way to think about software development – and has done so negatively: enormous ressources have been thrown into projects overloaded with advance specification of every imaginable feature, which has effectively prevented any dialogue between user and manufacturer and any feedback during the programming process (see Abrahams 1988). According to Paul Abrahams, this hampers not only the development of military software but software engineering in general because it is an “unvoiced assumption that the software is being built to military specifications«, and because “the reasonableness of those specifications« is accepted tacitly (p. 481).

The trend reminds strikingly of the ERA / UNIVAC experience (see Box X), though repeated on an immensely larger scale. There are thus historical parallels to Abraham’s claim that the military orientation is hampering and ineffective, producing much “less knowledge per dollar« than would be the case in a feedback-oriented organization of development. But “costs being not an appropriate« criterion (!; explicit DoD statement quoted by Abrahams), diminished effectiveness is balanced by abundance of dollars. “Pentagon style« software hence becomes quantitatively dominating to such a degree that it also acquires structural dominion. We may guess that the ensuing curtailing of engineering and computer effectiveness will in the long run be conquered by competition from civilly based development – but as long as competition is distorted by the availability of unbounded resources on the military side current trends are likely to continue. The

Things *need* not be like this. In the recent history of mathematics examples *can* be found where a whole branch of mathematics has had to be developed in order to solve a practical problem – according to insiders in the field, for instance, Pontrjagin derived his branch of control theory from the problems of missile guidance[36]. Thus, "things *need* not be like this". But as a rule they are. If we refer back to the introductory aphoristic question, at least part of the reward received by mathematics for prostituting itself to the military sector is paid out in counterfeit coin.

Up to this point we have discussed the involvement of mathematics with the military system as motivated by the applicability of mathematics. Especially in the U.S. but in other places too, another source of involvement exists which may perturb the picture: The funding of research, including mathematical research, in order to further the integration of universities into "the life of the nation" – to use the nice words by which Vice-President Hubert Humphrey described the incorporation of universities in the military-industrial complex[37]. The issue is thus purchase not of know-how of military relevance but of ideological, political and moral loyalty. This, however, is mostly not realized by critical observers – nor, in many cases, by those who are bought. Some mathematicians enjoy telling about how they have palmed off their pure-mathematical hobbies on the "stupid colonels" as possessing military potential – caring solicitously, however, not to pique the man with the cheque-book by politically offensive conduct. In private they are proud of having tricked the

self-defeating character of military influence in the field stops being self-defeating when society as a whole is completely militarized – not because the negative effects are vanquished but because they are carried by society as a whole in the form of inadequate technology and curtailed welfare.

[36] It may, however, be of importance in this connection that Pontrjagin the topologist *set himself* to the task. Similarly, many of those advances in early computer science which are often credited to military influence can be traced directly to the person of John von Neumann (cf. Goldstine 1972: 329-332 and *passim*).

[37] Quoted from Serge Lang (1971: 73). That institutions and not only individuals are (still) bought will be seen in the list of 10 "grand benefactors« to the 1986 International Congress of Mathematicians held in Berkeley. Among these we find Department of the Air Force, Air Force Office of Scientific Research; Department of the Army, Army Research Office; and Department of the Navy, Office of Naval Research (*Proceedings ... 1986*, p. xvii, cf. ii). Nobody can expect to get results of specific military value from the arrangement of a mammoth congress; only the loyalty of the profession as a broad national (and even international) average can be in question.

destructive apparatus out of funds by parading their Hilbert-space inquiries as space research. Others, conversely, are proud of their participation in “the life of the nation”, and are delighted that their research, the futility of which they had regretted, seems after all to be of national importance. Critically minded observers, finally, see the prevalence of military financing and grants as a proof that all science is thoroughly militarized.

At times it may be difficult to know whether a grant is given in order to obtain the ideological compliance of the scientist (and *university teacher,* which may in fact be the key point), or because the integration of a seemingly esoteric detail in a particularly sophisticated military project is anticipated. In both ambiguous and unambiguous cases it is obvious, however, that those resources which are now channeled to fundamental research through military budgets in order to serve the intimidation and ideological vassalization of mathematicians are no more scientifically productive than if they had been given directly.

6. WHAT CAN, AND WHAT SHOULD BE DONE?

Mathematics as it developed historically until the beginning of this century was no offspring of war; this is what follows from Chapters 1-3. The increasingly total character of military preparation and warfare, in combination with the scientific-technological revolution, has led since then to escalated military influence in mathematical research and to important military exploitation of mathematical knowledge, though until today without determining the overall development of mathematical thought and theory formation – cf. Chapters 4-5.

As far as only the logic of research is concerned it also emerged from the discussion in Chapter 5 that mathematics could develop quite as well or better in a peaceful world if supplied with the same or even with somewhat smaller resources (a trivial conclusion, had it not been for the contrary claims of too many apologists). Mathematicians are thus not dependent on the commerce of killing in their striving for the advantage and the progress of their science. That may ease the bad conscience of those who believe themselves to belong to a morally corrupt science.

Mathematics, however, does not exist in abstract logic alone but in the real world with its very real threats and military blocks. Similarly, mathematicians belong to a profession and not only to a science – and at least if we include in the class of mathematicians not only those doing genuine mathematical research but also those trained in mathematics at university level and applying it more or less creatively, a large proportion of this community will be found on the military pay-roll. Let us consider the implications of these realities, concentrating upon the situation of mathematicians of our own block – those of the socialist countries are in a better position to assess their own dilemmas.

Mathematicians calculate the "decapitation" of the Soviet Union in a nuclear First Strike (and not only U.S. mathematicians take part!): They calculate the techniques of the Strike, especially the precision of "our own" missiles and thus their ability to destroy those of the adversary in their silos, and the acoustical under-water localization of adversary atomic submarines (two necessary measures if an adversary is to be robbed of a deadly second strike); they calculate the miniaturization of H-bombs and the optional maximization of explosive force or radiation effect through precise calibration of the temporal progress of ignition, fission and fusion processes; they calculate the "vertical proliferation", the proliferation of nuclear vehicles which from one year to the next becomes increasingly unverifiable[38], and augment the range of missiles through improved thrust chamber geometry and that of long-distance cruise missiles through the development of diminutive, high-efficiency jet motors; finally, they calculate the total strategy of the first strike, accepting the death of 30 to 60 millions of Americans as "admissible losses", regarding the destruction of Western Europe as consumption of a "dispensable item", and passing over the killing of perhaps 150 millions of Soviet civilians as "collateral damages".

This is probably the most scaring example of the involvement of mathematics in the preparation of war, yet only one example. As already touched at, since the 1940es many mathematicians have been employees of the armed forces, have taken part in military research projects or have worked on military grants; many mathematicians were one way or the other brought to ideological and political compliance; and a few theoretical specialties were even created or experienced essential new developments in interaction with military needs. On the whole,

[38] In Summer 1988, after the agreement on land-based intermediate range missiles, the anxiety of the Reagan administration to avoid the inclusion of sea-based missiles in further agreements underscores that these considerations have conserved their full validity in spite of apparent changes of policy.

XVII. The loyalty market

The regular use of research funding as a means to buy loyalty is demonstrated by Serge Lang (1971). He presents the connections between the Department of Defense, public research funding in general and universities through a wealth of cases where attempts were made to scare or discipline American mathematicians during the Vietnam War – and he points out what could be done through collective opposition.

One case is that of L. Lecam and J. Neyman, two famous statisticians from Berkeley, who during the fifties and sixties had carried out unclassified research in statistics which was published in standard journals and supported by contracts with the Army and the Office of Naval Research (*inter alia*). In 1968, they signed together with others an advertisement in the *Notices of the American Mathematical Society*, stating that

> Job opportunities in war work are announced in the *Notices* of the AMS ... and elsewhere. We urge you to regard yourselves as responsible for the uses to which your talents are put. We believe this responsibility forbids putting mathematics in the service of this cruel war.

Even though the military value of their research could in no way be influenced by their signature, the two “disloyal« contractors were threatened by both Army and Navy that their contracts could not be prolonged – under the pretext that continuance would place them “in a most uncomfortable, and perhaps untenable« conflict of conscience. (Upon which Neyman commented that he “did war work during the Second World War. For 16 years, I have not done any war work. I prove theorems, they are published, and after that I don’t know what happens to them«).

The two statisticians made the threat public, which led to scandal, and it was then withdrawn. They made renewed applications to the ONR, Neyman for “weather modification studies promising benefits for Nation and humanity«, and both got new contracts without submission. Less famous scientists, however, were not as lucky, and in order to avoid future defeats the Director of Defense Research and Engineering issued a memorandum that all contracts *where the “non-technical« situation* (read: *the political loyalty of the contractor) was “uncertain«* should be submitted to special control of quality and productivity; for one thing, diplomatic reasons required that rejections should not emphasize political but only technical issues; besides, even politically disloyal researchers might happen to contribute “significantly to the country«. (pp. 53-58, full text of the memorandum p. 57).

mathematics may be the most important constituent in the infrastructure of the scientific-technological revolution and of contemporary scientific advance. The kind treatment of mathematics in the midst of cutdowns in all areas of civilian research (see Box XVIII) implies that the Reagan administration took the military commitment of mathematics for granted, and probably not quite unfoundedly.

Observation of the privileged treatment of mathematics as compared to most sciences by an administration oriented so unequivocally toward what Hardy caustically labelled “utility” introduces another challenge to the abstract logic of research (which may worry *some* mathematicians) is the question whether in a peaceful world mathematics would be “supplied with the same” or with only “somewhat” smaller resources.

"Why not?", we might ask naively. Mathematics would be useful for meeting all sorts of human needs, and not only those of the strategists and generals. Still, economists teach us to distinguish "effective demand" from "need", and sociologists will tell that not everybody "needing" is entitled to "demand". We shall therefore have to consider the conditions of the real world, which – as far as its "Western" part is concerned – is a highly organized monopolistic capitalism. Certain dogmatics will maintain that this system is driven *inevitably* toward imperialism and aggression, and that this is the only reason it invests in research and development. A thorough discussion of these two questions would lead too far; Here, we shall restrict ourselves to two brief observations. Firstly, the decisive question even for mathematicians must be that of the feasibility of a non-aggressive monopolistic capitalism (or, if that will not be possible, of the abolition of monopolistic capitalism), not that of the scale of mathematical research budgets once a peaceful world has been attained one way or the other. Secondly, armament is surely an important incentive for the U.S. to invest roughly 2 percent of their national product in research and development. The mechanisms of economic competition between firms and between states under the conditions of monopolistic capitalism are, however, of a nature which even without the incentive of so-called "defense" would secure automatically some two-third of the present R&D-budgets[39].

In the real world, as it exists and as it will go on according to current trends, mathematics is thus bound up with the military and the arms race; in as far as it is at all possible to make this world peaceful mathematics could, on the other hand, be disentangled without suffering loss of theoretical substance and inspiration (the question of the "logic of research") and without major "social" reductions (budget, manpower, social prestige, and what else may interest the members of a profession). Disentanglement need not, however, wait until an evangelical Peace on Earth has been achieved; on the contrary, disentanglement may contribute to pacification.

This imposes the obligation, to realize at our best that which *can* be realized, and raises the question *how* it can be realized.

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[39] Private estimate from comparative international R&D statistics. The mechanism is that firms will have no advantage from marginal sales price reductions under monopolistic (in the technical language of Anglo-Saxon economists: oligopolistic) conditions. Instead, competition will concern costs (involving among other things process development); product development and differentiation (if only sham development through changes in the design of "this year's model«); public image; political protection (important not least in the armaments industry); etc.

XVIII. The Reagan Administration and mathematical fundamental research

THE BUDGET OF THE U.S. NATIONAL SCIENCE FOUNDATION

The table appears in an article on the budget of the National Science Foundation for 1983. Other tables in the same article show that the bulk of funding for mathematical research will continue to flow to basic research, which in real value is not increased but anyhow less severely cut than all fields in average (not to speak of programs in educational science). Also exempted from reductions are computer science, physics, chemistry and materials research. The real increase in mathematics falls exclusively on “special projects«, research activities which combine several mathematical domains and which seem to be decoupled from teaching.

TABLE I. NATIONAL SCIENCE FOUNDATION BUDGET
(Millions of Dollars)

	1979 Actual 1/28/80	Change (79–80)	1980 Actual 1/15/81	Change (80–81)	1981 Actual 2/8/82	Change (81–82)	1982 Plan 2/8/82	Change (82–83)	1983 Request 2/8/82
(1) Mathematical Sciences Research Support	**$ 22.8**	**9.6%**	**$ 25.0**	**13.2%**	**$ 28.3**	**10.3%**	**$ 31.2**	**8.7%**	**$ 33.9**
(2) Other Research Support (Note A)	761.0	7.5%	817.7	6.8%	873.7	−0.3%	870.8	9.5%	953.4
(3) Education, Information, Foreign Currency Program (Note B)	88.4	7.9%	95.4	−15.5%	80.6	−61.9%	30.7	−27.0%	22.4
(4) Program Development and Management (“Overhead”) (Note C)	54.7	6.4%	58.2	1.7%	59.2	7.3%	63.5	-0.6%	63.1
(5) Totals	**$926.9**	**7.5%**	**$996.3**	**4.6%**	**$1041.8**	**−4.4%**	**$996.2**	**7.7%**	**$1072.8**
(6) (1) as % of (1) and (2)	2.91%		2.97%		3.14%		3.46%		3.43%
(7) (1) as % of (5)	2.46%		2.51%		2.72%		3.13%		3.16%

NOTE A. Scientific research and facilities (excluding mathematics and science information). National and special research programs, and national research centers. Support for mathematics has been excluded, cf. items (1) and (3).
NOTE B. The programs in this group are ones in which there is some support for projects in every field, including mathematics. The foreign currency program involves both cooperative scientific research and the dissemination and translation of foreign scientific publications. Foreign currencies in excess of the normal requirements of the U.S. are used.
NOTE C: This heading covers the administrative expenses of operating the Foundation; the funds involved are not considered to constitute direct support for individual projects.
(*Notices of the American Mathematical Society* 29 (1982): 238).

For such questions, physicists are traditionally more receptive than mathematicians. Since Hiroshima and Nagasaki the whole mythology of their field (understood as those parts of its history which are known by everybody) tells them that they stand “one foot in jail”. Some years ago, one of their number formulated sarcastically that “a member of the physics enterprise can minimize his possible contributions to military needs by either not teaching or by teaching poorly, and by either not doing research or by doing research unrelated to winning advances in basic or applied knowledge” (Woollet 1980: 106).

The second half of the aphorism refers once more to the network character of scientific knowledge: Concepts, methods and techniques may well have been developed in order to gain command of one, perhaps totally abstract domain; yet no warranty can be given that in military contexts they will not suddenly win concrete, destructive significance. The first half, however, points to something which we only touched in passing so far. Until this point, indeed, we only considered mathematics as a body of knowledge and as a researchers' community. Many mathematicians, though, also teach and thus educate students, of whom many, once they have graduated, go neither into fundamental research nor to school as teachers but instead into applications – not least with the military. In this connection it is worthwhile remembering that the German *Diplom-Mathematiker*, the mathematician trained to go into applications, was invented in the Third Reich (cf. Box XIX).

The responsibility of the mathematician must hence be discussed from two points of view: The responsibilities of the researcher, and those of the university teacher. On the first question one preliminary remark should be made. Many of those scientists who discuss the question of responsibility insist that “the basic reason for the irrationality of the whole process” of the arms race is the influence “of different groups of scientists and technologists”. Thus, for example, Sir Solly Zuckerman[40], for many years scientific advisor first of the British Minister of Defense, later of the Prime Minister. Such self-gratifying opinions on the part of a scientist are understandable, but none the less exaggerations. The scientist is *co*-responsible if he accepts (or even seeks) the role of a insensate and unscrupulous instrument. Still, responsibility is not diminished by being shared.

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[40] Zuckerman 1982: 102-106, quotation from p. 103. In order to drive home his point more convincingly, Zuckerman takes care only to mention the “soldier or sailor or airman«, i.e., the military professionals, as alternatives to “the man in the laboratory« when assigning responsibility.

XIX. *Diplom-Mathematiker*: Mathematicians for "State, Defence and Economy«

On this question, Horst-Eckart Gross writes to us:

The curriculum for students in physics and in mathematics (instituting the Diploma Examination as well as the "*Diplom-Mathematiker«*) was announced by an instruction from the Reichsminister für Wissenschaft, Erziehung und Volksbildung August 7, 1942, and published, e.g., in *Studium und Beruf* **12**:9 (September 1942), 97-100. As reason for the innovation it is stated (p. 97) that "the increasing claims of the State, the Wehrmacht and the Economy on physicists and mathematicians necessitate that the education of future representatives of these disciplines be put on a new basis«. The reform was the result of a long discussion, though beginning, it is true, only after 1933.

In the article "The New Syllabus and Examination System for Industrial Mathematicians in the Greater German Empire" by Lois Timpe, published in *Zeitschrift für die gesamte Versicherungswissenschaft* **43** (1943), 65-71, the author explains: "The moves toward realization of the *Diplom-Mathematiker*, which had already been begun by the beginning of the War but then got stuck because of war conditions, were driven forward anew from Autumn 1941 thanks to the praiseworthy initiative of the responsible commissioner and has now been brought to a successful conclusion«. From this it is obvious that plans were already in store, but that the Ministry regarded the question to be important enough for giving it the necessary attention even in 1942, that is – given the date – that the reform was considered important for the War. If the lack of mathematicians at the time and the increasing use of mathematicians and mathematics in armament is taken into account, this is indeed obvious.

(Private communication)

Co-responsible implies *responsibility*.

These observations do not abolish sociologico-structural explanations of the involvement of science and scientists. Questions of responsibility are, however, always personally directed: *I* am responsible, because nobody but I can respond for the way *I* act under the given conditions. Knowledge of causal explanations will not exonerate us from responsibility; it tells us how to act in order to meet our responsibility as efficiently as possible.

How, then, can the mathematician use that latitude for personal action which may be wide or narrow but which is always there?

As long as we inhabit States where we cannot be sure they will not use their military potential for aggression, to subjugate other peoples and States and as a tool for political blackmail, one should begin at the negative pole: What can be avoided?

One can avoid to have one's mathematical problems formulated by the military. That is:

Some mathematicians work directly in the military establishment or in armament corporations to translate the problems of their employers into mathematical questions (as once the scientific academies). One need not be one of them.

Others, often highly qualified university mathematicians, take up these mathematical questions, take care that many mathematicians contribute to work them out theoretically, and eventually combine the results and canalize the information back to the military sector (even this was part of the classical function of the academies). Mathematical results that can be argued to be neutral in themselves are thus, through selective communication and adequate combination, made partisan. Nor does one need to belong to this group.

Finally, a large number of university mathematicians and graduates are caught in the net of the second group[41]. Whether one belongs here may at times be difficult to ascertain. Often, however, keeping open eyes and ears may give hints whether one's work fits into a larger whole of military interest.

One may also avoid transforming international scientific cooperation into a battlefield of the cold war. This last negative imperative leads, through reversal, directly to the first positive possibility: The protection and amplification of international scientific cooperation, aimed at mutual benefit and mutual understanding may contribute to stabilize or re-establish the *détente*. As formulated by Oswald Veblen, then President of the American Mathematical Society at the opening of the International Congress of Mathematicians in 1950 (*Proc ... 1950*: 125): "To our non-mathematical friends we can say that this sort of a meeting, which cuts across all sorts of political, racial, and social differences and focuses on a universal human interest will be an influence for conciliation and peace".

Even the next possibility arises by reversal: Counter-expertise. One example of this is presented by the critical analysis of the calculation of the First Strike. When the advisors of the President and of the Pentagon claim that a First Strike is possible at the maximal condition of 30 million killed American civilians, then independent, highly qualified experts are required, for one thing in order to make the calculation and its conditions public – nobody can expect the Pentagon to advertize the scheme of 30 million fried Americans. But they are also needed if anybody is going to uncover the real dimensions of the catastrophe stored in the military incubator: Only those at least equalling the strategic planners in

[41] This three-level structure of the military entanglement is clearly visible in the case of the *Mathematics Research Center – United States Army* of the University of Wisconsin. A meticulous investigation of the work and working of this institution will be found in *The AMRC Papers* (1973).

XX. The Kamke Appeal

September 23-28, 1946, the Mathematical Institute of Tübingen University organized a scientific symposium, "the first after the end of the War in Germany«. In his opening address, E. Kamke stated among other things that

> The physician receives not only a technical-medical training but also a moral education which allows him to use the most dangerous aids – knives, narcotics, poisons – only for the benefit of the ill. Similarly, it is urgent that scientists use their immense power, which can make them the masters of the life or death of nations, and even of Mankind as a whole, only for the benefit of nations and Mankind. In earlier epochs, qualification for genuine scientific research was the most prominent characteristic of the scientist; in future, however, this must be supplemented by something different: a particularly elevated professional ethos, an utterly sensitive consciousness of the consequences of research for mankind. It should be contemplated whether these moral requirements to the researcher's personality should be supplemented by organizational measures, of which the mildest would be the establishment of an international information bureau where all research in specific domains would have to be notified, no restrictions ensuing for the freedom of research.
>
> These problems are of such importance that they should be discussed at all occasions where scientists meet. We must engage ourselves with our total strength and our whole person, that in the future science will never more serve destruction but only the welfare of mankind.

This quotation from p. 11 of the *Bericht über die Mathematiker-Tagung in Tübingen vom 23. bis 27. September 1946* (Mathematical Institute, Tübingen University, n.d. [1946/1947]) was communicated to us by Horst-Eckart Gross.

competence will be able to document that the "decapitation" of the Soviet Union will probably imply the death of 150 million people in that country, and maybe to even more in Western and Eastern Europe. Finally, only those in better command of global questions than the strategic planners will substantiate the abstract insanity of the whole business: Abstraction from possible effects of the first H-bomb explosion on one's own communication systems and electronics; from the consequences of possibly wrong estimates of the survival percentage of adversary missiles; from consequential effects (like mass panic, hunger, epidemics, etc.) of the sudden death of 30 million Americans and many more severely injured by radiation; and from global climatic and ecological breakdown[42].

All this cannot be done by mathematicians alone. No discipline can do it alone, however, and mathematicians are indispensable when the many uncertainties of the project are to be evaluated – e.g., for evaluating the

[42] This passage is left as it was written in 1983/84. Since then counter-experts have, indeed, substantiated much of the criticism so thoroughly that even the military planners have been forced to take up, e.g., the nuclear-winter phenomenon.

XXI. International scientific cooperation: A way to restore the détente?

Several international congresses these last years have witnessed how international scientific cooperation was used as a pretext for a continuation of the political conflicts of the “international class struggle«.

That happened before in the history of our science. The exclusion of German mathematicians from the Congress in Strasbourg (formerly Straßburg) in 1920 was mentioned above. The solemn opening and closing addresses were held by Émile Picard: “How should we forget in this place the admirable conduct of so many of our teachers in the War which has just ended; their patriotic faith has contributed to the common victory which today allows us to meet in the city of Strasbourg«. Keeping open the question whether “sincere repent« would allow later generations of German mathematicians to re-enter “the concert of civilized nations« he added that in his opinion “to forgive certain crimes [*viz.* those of the enemy] would make one an accomplice« (*Proc. ... 1920*, xxvif, xxxii]. At 70 years distance we see how this double standard contributed to preparing the ground for the still worse derangement of “German Mathematics« and “German Physics« – as the hunger blockade and the exorbitant reparations of the same years created the “Versailles Complex« and thus made it easier for German fascism to gain a mass basis.

Not every mathematician needed 70 years to understand that the direction taken was insane, and that scientific communication should not be used to continue the World War. Already after the French-German war of 1870/71 had the Swedish mathematician Gösta Mittag-Leffler founded the journal *Acta Mathematica*, among other things as an appeal to and a means for conciliation between French and German mathematicians. As described in detail by Joseph Dauben (1980), he used the journal once more during and immediately after the War in order to “restore as rapidly as at all possible the cooperation between scientists, independently of political and national points of view«, as he wrote to Max Planck in October 1919 (*ibid.* p. 281; further quotations from Mittag-Leffler’s letters are brought in Box XXIII).

Similarly was Hardy, whose personal abhorrence at the “useful« service of science for mass murder and exploitation was noted above, active in making science useful for conciliation – against “the many imbecilities printed during the last year by eminent men of science in England and France« (letter to Mittag-Leffler of January 7, 1919; further information on Hardy’s activities and on the conflict between chauvinism and internationalism in science is given in Cock 1983).

As we see from the present quotations and from those in Box XXIII, Mittag-Leffler and Hardy aimed at general, broad cooperation. Attempts like those of recent years to use the interest in specific “cases« (be it quite justified) as pretext to interrupt broad international cooperation and thus to undermine the climate of détente are quite in the spirit of Picard and against that of Mittag-Leffler and Hardy.

uncertainty in the temporal and spatial precision of missiles when fired simultaneously in large numbers (as discussed by J. Edward Anderson [1981]).

Once more, the First Strike was only one example even though a most urgent issue during the Reagan era. But also in other fields will the competence of scientists be useful, not least that of mathematicians. Both in the example just discussed and in many others, they may perform necessary new research; they may popularize known research results and so translate abstract knowledge into directly applicable information for peace movements – not only results from their own discipline but also from such areas where their professional training allows them to penetrate faster than laymen; and they may use still other aspects of their specific competence, be it familiarity with libraries and library use, be it training in mediation between abstract and concrete thought or in the systematic collection of information, be it still other skills of the intellectual by profession. Most of it will certainly not be describable as mathematics. Nor was, however, most of that which mathematicians made in World War II ("not one thing that was publishable", cf. above, Box VIII), which did not prevent it from being most useful for the purpose.

Related to the question of counter-expertise is that of peaceful perspectives for mathematical research. As discussed above large areas of mathematics are completely unspecific as regards practical affiliation. Other areas, however, are of specific relevance for military application, and – more important – certain institutional habits favour information exchange between the warlords and specific mathematical research environments. Not only the military, however, knows of problems inviting to mathematical solution. Procurement with raw materials and resource conservation, the all-encompassing climatological and both local and global ecological problems, animal and plant production, medicine, and many fields of fundamental research, from physics to linguistics, can be presumed to procure mathematics with an abundance of problems for centuries (cf. Booß & Rasmussen 1979). Just as the mathematician may orient his research, in contents or institutionally, toward the armament pole, he may look in these directions.

Finally, mathematical researchers are also participants in the social process of research. That gives everybody the responsibility and the possibility to make clear to himself, to the colleagues, and to the public, what goes on in his own division:

– Which are the possible applications of the research which is pursued?
– In which ways can it be applied: Directly / specifically or indirectly / unspecifically? Is the subject, e.g., "harmonic analysis"; "fast Fourier transforms"; broadly applicable procedures for "pattern recognition" – or is it the specific problem of automatic terminal control of missiles in search of adversary missile silos?
– In which way is the applicability communicated, i.e., which are the sources for possible external inspirations, and to which addressee and in which form are results canalized; ? Does one send offprints of published papers to colleagues, or do results go to the Air Force (as offprints or as classified reports) with careful explanation of the relevance of a new algorithm for the mining of seaways?
– Which are the personal and institutional affinities, loyalties and dependencies

XXII. When science goes advertising: Embarrassment and frankness

Since the Vietnam War, the public-relations agencies of the scientific establishment have become discrete on the question of military application. Close reading of their publications will, however, disclose the rattling of the hidden skeleton. Thus in a report from the U.S. National Science Foundation:

> ... The problem of visual perception by computer is a minefield of sub-problems. At the simple end of the scale, systems already exist for comparing what the robot's eye would see with stored pictures; these are used today to guide a *missile* toward a target. The problem of interpreting objects in photographs collected routinely by weather and *surveillance* satellites is somewhat more difficult, but still feasible. Reliable techniques have been developed to automate parts of these photo-interpretation tasks. Similar systems can also be used to spot *roads*, *bridges* or *railroads* in aerial photographs.
>
> (*Science and Technology* ... 1979: 248; emphasis added)

P. 249, the same report speaks of the computers – once publicized as prototypes of the beneficial results of war research and development – as "initially the esoteric tools of a small scientific community«! Who could find a more innocent name for the Oak Ridge, Los Alamos and Argonne atomic-bomb laboratories?

created, e.g. by marginal funding?

Usually, such questions are hidden under a thick cover of academic discretion. If we are to rid our world of war and our science of corruption it is, however, crucial to end this silence – be it at the cost of consideration and tact among colleagues[43].

We shall not discuss the options of mathematicians as researchers at greater length. There is, however, another side of their professional life, that of teachers at the university level. Should we say with Woollett that the only ways not to contribute to military needs are to abstain from teaching or to teach poorly?

If somebody abstains from teaching, the occupational situation of the day will guarantee that somebody else will soon be found to do it. General-purpose teaching cannot be boycotted as can participation in SDI-research[44]. Abstention may ease bad conscience but has no further effect. Poor teaching is no better. Who teaches poorly will only undermine the respect for himself as a person, and thus also for his political position, among students as well as colleagues.

[43] One may get funny reactions. "Some don't approve of sexual intercourse, some are opposed to card-playing, and JH cannot accept what I do«, as one professor commented in the weekly of the Danish Technical Highschool when his work on antennas for use in the Vietnam war was questioned.

[44] See *Scientific American* **254**:1 (January 1986), 48 (European pagination), "Signing off".

According to these considerations, in order to be able to act efficiently for peace one has to teach well. Good teaching, however, is only a necessary background and has of course no effect in itself. What should one then *do* as a teacher?

Firstly, one may once more *avoid*. Truly, one cannot avoid teaching mathematics of military relevance. Mathematics teaching (as long as it remains *mathematics* teaching – the teaching of specific mathematically founded techniques e.g. to bomber's crews is irrelevant here as not being the task of mathematicians) always transmits multivalent and flexible concepts, methods and techniques, which are neither coupled to specific applications nor shielded from them. One can, however, avoid presenting the mathematical enterprise as something associated organically or inevitably with military inspiration, application or funding and the career of an army mathematician as a natural and laudable option for a young colleague. One need not, as done so often, illustrate the problems of Bayesian statistics uncommentedly by the targeting of gunnery, nor use in the same way the perturbations of a missile trajectory to exemplify the application of infinitesimal methods. One need not flaunt operations research and computer technology as paradigms of the blessings of war research (though covering up their ties to institutionalized mass murder is certainly no better).

So much about the ideological impregnation to be avoided. Similarly, one can and should avoid the corresponding real-life behaviour: one should avoid the part of an impresario introducing via their dissertation work students to the armament industry. On this point, the dependence of students imposes very strict circumspection upon the teacher.

It is also possible to act positively. One cannot, it is true, solve those moral dilemmas for the students to which they will later be exposed; but one can assist them in developing the sensitivity to discover the dilemmas and the ability to solve them.

It is well-known that many of the physicists taking part in the Manhattan project opposed the use of the atomic bomb against Japanese cities, and that even more turned against the military use of nuclear energy after Hiroshima. The *Bulletin of the Atomic Scientist* and the "World Federation of Scientific Workers" both owe their origin to this opposition movement. Less commented upon is the absence of such documented feelings and initiatives among the engineers from Dupont, Union Carbide and General Electric carrying the project to technical completion. To be sure, the physicists' protests did not save Hiroshima and Nagasaki. But they have contributed to making large strata of the world

XXIII. Mittag-Leffler

Mittag-Leffler to Ludwig Bieberbach, April 23, 1919

... Soeben erhielt ich das Heft 3/4 des 3. bandes von "Mathematischer Zeitschrift", wo ich Ihre schöne Abhandlung "Ueber eine Vertiefung des Picardschen Satzes bei ganzen Funktionen endlicher Ordnung" finde. Bitte schicken Sie mir gütigst einem Separatabdruck. Ich möchte Ihnen auch einen Vorschlag machen, welcher ich glaube sowohl in Ihrem Interesse als in Interesse Deutschlands liegt. Schreiben Sie mir einen Brief, welchen Sie zum Beispiel ungefähr so anfangen: "Ich habe neulich eine Untersuchung ausgeführt, die ich unter dem Titel 'Ueber eine Vertiefung des Picardschen Satzes ...' in Mathematischer Zeitschrift publiziert habe, und Sie vielleicht interessieren wird". Hiernach teilen Sie mir *ausführlich* die schöne Untersuchung mit, die Sie über meine $E_\alpha(x)$ Funktion vorgenommen haben. Es wäre auch gut, wenn Sie mir gleichzeitig die Untersuchung mitteilten, die Sie über $\alpha>2$ angestellt haben (cf. pag. 185 in Ihre Abhandlung). Es wäre sehr Zweckmässig, wenn Ihr Brief in französisch abgefasst wäre oder, noch besser, in englisch.

Ich habe mir die Aufgabe gestellt die jetzt abgebrochenen internationalen Wissenschaftlichen Beziehungen, so viel an mir ist, allmählich herzustellen. Mein Vorschlag an Sie bildet ein Gelenk in diesen Bemühungen. Ich bin der Ueberzeugung, die Mathematiker müssen die Leitung für ein solches Streben übernehmen. Meine Zeitschrift ist für diese Aufgabe in einer günstigen Lage. Die Bände, die ich in den Kriegsjahren publiziert habe, enthalten Artikeln von den beiden Kriegführenden Gruppen.

As we know, this touching letter from the 73 years old Mittag-Leffler to the young Bieberbach did not prevent the latter from becoming some years later the leading figure in the racist "German Mathematics«.

Mittag-Leffler to Max Planck, October 7, 1919

Die Hauptsache ist zuerst die wirkliche Stimmung in den höchsten wissenschaftlichen Kreisen kennen zu lernen um dann später so zu handeln, dass man in so kurzer Frist wie nur möglich das Zusammenarbeiten der Männer der Wissenschaft, unabhängig von politischen oder nationalen Gesichtspunkten, wieder herstellen mag.

Ich gehöre einer Wissenschaft, die sich besser als jede andere für die Aufgabe eignet an die

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population sensible to the dangers of nuclear war, and so perhaps averted new Hiroshimas in Korea, Vietnam or elsewhere.

We have no possibility to know the reason why the engineers remained mute at least as a group: Was it fear of dismissal or of repression on the job? Lack of a comprehensive outlook? Absence of the aspiration to work up such outlook? Isolation on the job not permitting organized communication and manifestation? Nor do we know the circumstances under which our students will eventually have to work, whether they will be similar to those of the "physicists" or those of the "engineers". We cannot protect them against repression on the job or against that deliberate blindness to the consequences of one's work which one may develop to protect oneself in this situation; we can, however, take care that blindness will not be the only option open to them. We cannot prevent that scientists are employed in industry as narrowly specialized functionaries; but

Spitze von solchen Bestrebungen zu treten. Ich bin auch in der glücklichen, wenn auch nicht sehr verdienten Lage überall in den Sitzungen der ersten gelehrten Gesellschaften in jedem Lande teilnehmen zu können, und dadurch auch in den übrigens sehr seltenen Fällen, wo ich nicht persönliche freundschaftliche Verbindungen seit Jahren habe, doch überall mit den leitenden Persönlichkeiten in Verbindung treten zu können. Offenbar sehe ich es deshalb als eine Pflicht an diese Umstände zu benutzen um den Ziel näher kommen zu können, welches jedem Manne, für welchen die Förderung der Wissenschaft die höchste Aufgabe seines Lebens ist, ganz besonders am Herzen liegt.

Mittag-Leffler to G. H. Hardy, January 25, 1919

... I agree with you that we as mathematicians need to be at the head in "the task of the reestablishment of friendly relations" between the men of science of all countries. I also hope to be able to aid such reestablishment of scientific relations through my journal *Acta Mathematica*, which in the area of mathematics has been able to maintain such relations during the last four terrible years.

Mittag-Leffler to Max Planck, March 30, 1919

... Die Männer der Wissenschaft müssen sich vor aller Politik abhalten und nur auf die rein wissenschaftlichen Gesichtspunkte denken. Wenn die Wissenschaft nicht hoch über das jetzige politische Elend aufrecht erhalten werden kann, geht alles zu Grunde. Mein ganzes Streben geht dahin so viel wie nur möglich für dieses Ziel zu wirken.

In the context of 1919 the expression "political misery of the day« shows that Mittag-Leffler's efforts to keep mathematics aloof from politics was not meant as an ivory tower policy but the necessary consequence of sincere moral responsibility.

(All quotations are from Dauben 1980)

we can make them see the wider connections of science and thus also the real inner connections between scientific subjects and those between science, applications and consequences and so keep open for them the psychological possibility not to be absorbed by narrow specialization, We must make them discover the double character of scientific-technological work: Not only knowledge and application of knowledge in abstract technical contexts but knowledge which is known by specific people under specific circumstances, and technology which is operated under specific societal conditions and applied for specific purposes.

Mathematics teaching will hence contribute to the conservation of peace *by being humanistic*, by caring that the future applier of mathematics will not be a passive transmission link between commissioner and work product but an active human person who understands his own activity in broader context and consequence. If it is not to remain an empty phrase this "broader context" must, however, be presented *concretely* to the students during their studies. The broad perspective must be present in and integrated with the complete course of studies – a separate course on “humanistic values” or “mathematics as a liberal art” will have little value if counteracted by the implicit message of the main body of teaching.

In the wake of these considerations another look at the concept of “organized segmentation” will prove illuminating. It was argued above that the segmented character of the scientific-technological system in combination with organizational principles set not by conscious participants but by the conglomerate of economic, bureaucratic and political power would cause the standard according to which it is so indubitably efficient to be set by those instances. Now, both bureaucratic and commercial structures tend to protect their own interests without considering global concerns. Public authorities, even when not themselves dependent upon bureaucracies or big business, are rarely competent to go into the subtle mechanisms of the system. Only participants have a chance of knowing it sufficiently well for doing so – but only if they are able to transcend their “naive” specialist’s role. The condition that participant’s may interact with the public and with democratic public authorities to avert global catastrophes hence coincides with the condition which was sketched for mathematics teaching to operate in favour of peace.

In the end we should remember that mathematicians are also citizens. That imposes the same responsibility upon the mathematician as upon everybody else. In the situation of the day, however, one only honours one’s moral obligations by doing one’s best. The mathematician is thus responsible for using also his *specific* possibilities – that is, the *civic* duties of the mathematician implies that one discharges also one’s moral obligations as a researcher and as a teacher *and* integrates the citizen, the researcher and the teacher with one another.

That may sound easy, and quite a few mathematicians will heartily agree that they possess special qualifications for being good citizens. They need not be wrong: Analytical and synthetical thought, distinction between and mediation between the abstract and the concrete, fantasy and stubbornness – all these abilities belong to the job, and all are useful for the participation in democratic political life. Many mathematicians will also be acquainted with a number of diverse applications of their subject and so have accumulated useful insights outside their specialty.

Mathematicians, however, also tend to have a handicap. The particularly important position of the logical argument in mathematics easily leads to the opinion that everything not belonging to mathematics, particularly political and moral thought and convictions, is illogical and beyond argument. Furthermore, it is not uncommon that mathematicians mistake this epistemological dichotomy between demonstration and subjectivity for a social dichotomy and, confusing that which belongs to the *mathematician* with that which belongs to *mathematics*, take their own inveterate persuasions and prejudices for objective truth[45]. In order to make his special qualifications fertile the mathematician must surmount this professional arrogance. He should not dismiss the participation in broad political movements as unworthy of his intellectual merits. He should realize that the rationality of mathematics is but one embodiment of a more general category of rationality, allowed and conditioned by the specific object of mathematics; and he should accept that rational discernment is also possible in the moral and political domain, but that it presupposes, here no less than in his own field, systematic engagement and sobriety in the argument.

Mathematicians, if they want to engage themselves for peace, must understand themselves as participants in a larger, common enterprise. Neither better than others nor inferior, but their equals in rights, in merit, and in responsibility.

[45] This comfortable complacency may have much to do with the outcome of a survey of scholars' political attitudes conducted in 1969, at the height of the Vietnam War (Ladd & Lipset 1972). Mathematicians were found not only to the right of average faculty of all fields (as were all scientists except physicists); they were also perceptibly more right-wing than scientists in general. As in all other fields, "achievers« (faculty at elite universities having published 10 or more professional works during the last two years) were more left-wing than average for the field; but even they were less so than achievers in all other sciences (engineering apart), and while "achieving« physicists would rather be "very liberal« (33%) than "liberal« (27%), the numbers for mathematicians were 9% and 44%, respectively.

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