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MATHEMATICS IN THE UNIVERSITY AND MATHEMATICS IN INDUSTRY - COMPLEMENT OR CONTRAST?

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Mathematics in Industry - Mathematics in the University: Do there exist two different kinds of mathematics?

Mathematicians who have been educated in the Bourbaki tradition will have no difficulty in answering the question of what mathematics really is (if the expectation of the inquiring person is not too highly philosophical). They will say: Mathematics consists of deducing theorems from self chosen axioms. The definition-proof style in this concept is already well known (indeed, "familiar" would be an exaggeration) among the high school pupils today. This concept of mathematics influences the mathematical education at the universities not only of the mathematicians themselves but of the other scientists and engineers. When our students leave the university, they have learned this approach and usually they want to go on practicing it.

BUT: Their wish is very rarely fulfilled. To be sure, reports, published by the Labor Ministry of the Federal Republic of Germany on the success rate of applicants in finding a job, assure us that in 1983 nearly every mathematician with his Diplom found a job, but these excellent prospects cannot hide the fact that such mathematicians rarely find a job which allows them to use their mathematical training directly; in other words, they cannot continue doing what we have taught them to appreciate (at least I hope so!) at the university. What remains on the credit side of the ledger of a traditional mathematics program is the capability to think logically. But the acquired knowledge, concerning mathematical theories and methods, is hardly ever asked for.

All this is not new - it is as old as the habit of (at least, the German) mathematicians at the universities hiding their heads in the sand when confronted with such facts.

We read in the statistical reports, 1982, published by the Federal Republic of Germany that there are more than 30.000 students in mathematics. Considering this fact, I feel that we cannot justify such a policy of "there cannot be what there must not be!" Therefore, we shall try in the following to find a diagnosis - at least as far as the Federal Republic of Germany is concerned - and even develop some possible therapies afterwards.

To me, the first question seems to be: Is there perhaps little or no mathematics at all needed in ones vocation? Or is it a different kind of mathematics?

My sources for answering this question are:
- 12 years of activity at a national research center;
- the management of a trial experiment during the past three years which investigated the possibilities of continuing education in mathematics for engineers, physicists, and mathematicians and which examined the implications for developing new (applied) directions of study in our Master program;
- and finally, experiences gained by a project running about a year with the aim of establishing a "working team in technomathematics". This working team tries to improve the cooperation between the aforementioned "two types of mathematics" on different levels. (This project is supported by the VW foundation.)

In my opinion, all these sources form a fairly homogeneous picture of the situation as it is and how it could be. Therefore I want to present the results of our research to you as well as some proposals in order to change this situation. Right away I will confess that all these proposals serve but one aim: to decrease the gap between studies and professions and first of all to provide our graduates with better chances in their job especially with regard to quality and enjoyment.

Let me repeat my question: Is there mathematics in industry and if so of what kind is it? As I have already mentioned I acquired my knowledge by that "Modellversuch" on continuing education. (Here I refer to the paper by M. Schulz-Reese.) In the beginning of our investigations, we visited about 25 research and development departments of German industries. Our choice was random and only systematical in that we left out the computer industry. We only investigated large or medium industries and visited research and development departments but no planning departments. We talked with people on different levels of the hierarchy, including the managing director as well as the simple engineer who worked alone on a problem. We talked with engineers, physicists, businessmen, and mathematicians and the results showed another picture than the one often drawn by industrial mathematicians during their occasional lectures at universities. (I am not quite sure about the psychological cause of this discrepancy.)

In addition to our investigations we asked 100 industrial firms to send their mathematical problems of interest in order to prepare this conference on "Mathematics in Industry". We got 60 answers with about 100 more or less distinctly formulated problems. (Compare the short report of Karl Hoffmann.)

Let me formulate the general conclusions of all this material as three "theorems":

Theorem 1

In industry, the role of mathematics is perceived neither as developing theories deductively nor as supplying convergence proofs to numerical algorithms, but as formulating and evaluating mathematical models of given practical problems.

Of course, it is a mathematical process to derive a system of differential equations for describing the behaviour of a shock absorber, even if technical and physical knowledge is needed to be able to do so. Of course, it is a mathematical task to discuss simple approximations in order to first get qualitative information if the original problem can't be solved directly, even if technical intuition is needed to do it. The numerical solution and the computation of data are obviously mathematical processes; the same is true for examining the relevance of data and subsequently modifying the underlying model itself.

Theorem 2

If mathematics is understood as in Theorem 1, the increase of its importance for industrial research and development during the last twenty years must be called revolutionary.

The reason for this is the immensely increased capability of the computers which allows a transition from the *real model to a mathematical one*. Voluminous formula collections (in Germany, for example, "die Hütte") have been replaced by nonlinear partial differential equations and their solution by finite elements.

In the following, I shall mention *several typical mathematical topics* of interest.

1) Nearly everywhere *optimization* is needed. Not the optimization as mathematicians normally like to consider, however, but "good-natured" methods where the function to be minimized is given only pointwise: For every point of the parameter domain you can calculate the value of the function, sometimes by long computer runs. But there are no gradients, no information on the analytic shape of the desired function. Often evolution strategies are used, which imitate the inheritance of good or bad characteristics and which were invented by a biologist. Mathematically, such strategies can be regarded as special cases of a random search method whose properties with respect to an averaged number of steps have been little studied by mathematicians. These evolution strategies certainly are not very efficient, but at least they produce some result - and which engineer has got the time to write a new program for every new problem? Normally, this aspect is neglected by mathematicians who are used to construct a special optimization method for every problem.

2) An often discussed topic is the *Finite Element Method*. For such methods, there are programs available with varying degrees of robustness and versability, which especially in small

firms are used as "black boxes" and therefore turn out to be rather inefficient or sometimes of no use at all. Here is a genuine need for continuing education - one wishes at least to be able to put sensible questions to the producer of software, or, even better, one wants to get rid of this "black box" dependence. There is also a demand for methods suited to non-linear problems.

3) There exists a great demand in the field of *stochastics*, too. A theory is needed for systems, in which the in- and output signals are stochastic processes. A good example is again that of a nonlinear shock absorber which is modelled as a system whose input signal (the street) can be interpreted as the trajectory of a stationary process and whose output signal is what the driver of the vehicle feels. For an analysis of this model, one needs a high level of mathematical knowledge not only from the field of stochastic processes but also from the fields of Fourier analysis and dynamical systems. This kind of mathematics has partly not yet been understood or the parts which are understood cannot be communicated to the engineer. As in linear algebra, there is a lack of elementary prerequisites, for example a reasonable conception of the meaning of mean value and variance. And here, we as mathematics teachers are guilty of another omission: We have given too little thought to what type of modern mathematics should be presented to our engineers. But this is another topic altogether.

4) From applications, there are more and more problems emerging which are actually questions in the field of *inverse problems*, although this relationship is not as yet quite understood. In this field, much has happened mathematically during the last few decades - just consider the theory of solitons with the accompanying problem of regaining the potential from the spectrum of the Schrödinger operator. Exactly in this form, the following problem will appear in practice: One wants to determine the condition of the bodywork of an automobile from the frequencies of an oscillating system (say, when the bodywork is subject to blows). Engineers call this an identification problem. Take as example a crash simulation of cars: The system

of car + driver is modelled as a system of springs and masses, the mass and spring constants being unknown. Several real car crashes are performed and afterwards one tries to determine the unknown parameters in such a way that the simulated system shows the same results as the real system. In order to do so, one has to draw conclusions from the solutions to the system - a problem which nowadays appears rather often, but whose mathematical treatment is certainly not in the final stages.

These examples show: Mathematics in industry does not only claim an essentially different understanding and therefore needs a different kind of mathematical education, but it also produces new research problems which so far have yet to make their influence felt in the mathematical research done at universities. Let me quote the geometer Branco Grünbaum from his lectures with the title "Lost Mathematics" (1975):

Through a concatenation of events I was led, during the past several months, to the realization of the following fact, which I find rather disturbing: In a considerable number of fields and professions, people are engaged in research of purely mathematical questions; we, as mathematicians, not only failed to answer those questions previously - we are even post factum unaware that anything has been happening. No trace of this sometimes sizable literature is found in the Mathematical Reviews or in the other mathematical survey journals. I find this situation distressing for many reasons, - but the most important one is that we are missing out on much beautiful mathematics. One aspect of the loss is that we are (generally) ignorant of many facts and theories - just because they do not fit into our (rather harebrained) curricula and the "mainstream of mathematics". Another aspect is even worse: Interesting, challenging and important mathematical problems are not considered at all, in many cases because the workers in other disciplines have neither the motivation nor the training to do so.

The above mentioned examples also point out: There is a lot of mathematical questions in the research and development departments of the industry which are interesting for education and research.

In Branco Grünbaum's quotation one can already hear the inevitable next question: Who does this mathematics?

Theorem 3

The biggest part of mathematical work in the research and development departments of German industry is done by engineers.

This does not mean that there are no mathematicians in these departments, doing mathematics in this sense. It only means that generally mathematicians do not play the main role in solving the mathematical problems arising in industry. Of course there are exceptions in special branches: For example there do exist strong departments in chemical industry directed by mathematicians. In the steel industry one can find groups of mathematicians - this is traditional since heat conduction is an old subject. In the electrotechnical industry mathematicians are the exception, but a relatively frequent exception. But, in the mechanical engineering and in the automobile industries, the situation is worse. There are firms, where about 100 engineers are busy performing calculations on very complex motors without a single mathematician around. In a research institute of an automobile firm which does extensive research for the future with a lot of computing effort, we found no mathematician at all. In the "theoretical department" of another automobile firm we found one mathematician. There are mathematicians working in these firms, but in the computing centers and not where mathematics is really done.

Why is this so? First of all, there is a deep mistrust of the technicians towards the mathematician. This mistrust has a long tradition. As early as 1740, the philosopher Christian Wolff wrote that "Mathematicians like to be satisfied by theory and technicians look at the theories of the mathematicians as lofty whims". Most emphatically, Frederic the Great states his opinion in a letter to Voltaire, in which he describes Euler's efforts in building his fountains at Sanssouci: "The lifting tackle was built according to mathematical calculations and as yet cannot lift a single drop of water up to 50 feet from its container. Vanity of vanities! Vanity of mathematics!"

And a last quotation from an English engineer in 1832: "The stability of a building is inversely proportional to the (mathematical) knowledge of its architect." If you add to this the remark of the President of the Technical University of Munich, who himself is a renowned theoretical physicist, that mathematics is like a study of *orchids*, then one can understand that this attitude has its adherents till this very day. And one can especially find them in the personnel departments of industry. The responsible managers believe and state out frankly that it is easier to teach an engineer mathematics than to teach a mathematician technical understanding. But, in order to avoid any misunderstanding, I consider this attitude wrong, but it is quite understandable. It happens sometimes that teaching assistants, i.e. graduate students of mathematics, have difficulties with exercises in modelling for the engineering students in the first year: actually they only want to find a δ to a given but arbitrary ε!

But nevertheless: This attitude is wrong - mathematics is not at all that simple - and therefore it is even harmful for the industry to harbor such views. Sometimes, employees in industry use old fashioned - which means slow or unstable - methods. They learn by testing and by the method of trial and error, even though ready answers and theories already exist. Several problems are thought to be mathematically inaccessible, even though there are possibilities for insight and understanding. Two large fields in this respect are the above mentioned fields of inverse problems and free boundary value problems.

So much for a survey of our results; these results can be proven by experiments which can be repeated. In the following deliberations, I shall draw conclusions, state my conjectures on the reasons for the present situation of the mathematician in industry, and make suggestions for improving his role.

What conclusions should the university draw from the preceding three theorems?

First of all: The above mentioned distrust of industry towards mathematicians has a strong reason: There is a certain lack of readiness or capability of young mathematician to understand the language of the technician (a little exaggerated we could say that pure mathematics improve the capability to think logically but hinders the capability to communicate). The mathematician asks for a precise mathematical formulation and is suddenly confronted with springs, signals with noise, or modal analysis. He wants to do university mathematics but is supposed to set up and evaluate models for non-mathematical problems. To be able to do this he needs fundamental knowledge, knowledge of the language used in an area of application (for example in mechanical, electrical engineering or in technical physics). In a magazine advising high school students from November 82, one can read: "Mathematicians are in competition with businessmen, engineers and scientists with a solid professional education in mathematics. In order to have a successful start in his profession, the mathematician should be advised not to get too much absorbed in special mathematical studies but to become rather extensively engaged in a non-mathematical subject."

This could also be interpreted in the following way: There is a need for mathematicians - but we have to establish a market for them first. They are in competition with computing engineers; so let us train them to win this competition, let us prove to industry that mathematicians - well-trained mathematicians - are able to solve mathematical problems better than engineers whose mathematical knowledge is often very specialized. And if that means that we must waive some training in a few special mathematical areas, it does not mean that we should narrow or specialize the overall training nor make it any less rigorous. We are not talking about a narrowly based course of study. By the way what could be called narrow? A course of studies which entirely specializes in the problems of e.g. projective geometry from the 5th semester onwards and leads to the "borders of research" or a course of study that teaches the student the fundamentals of functional analysis and numerical mathematics, along with acoustics and electrical engineering so that he is able to give at least a small contribution to tomography in his Master Thesis? Therefore it is incumbent on the student *to learn the language of at least one field of application* - in this context, it would mean a technical field, but in general it could also be a field in economics, medicine, biology, etc. in order to be able to develop and interpret models.

The other requirement is *to learn the tools for evaluating the models*. Besides a profound knowledge in analytical and numerical methods, such a requirement means also the knowledge of how to use a computer. In my opinion, it would be sufficient for a mathematician to know how to use it and leave theory, design and construction of a computer to the computer scientist. (You don't have to study thermodynamics in order to be a good car-driver. However, fundamental knowledge of how the main parts of the car work certainly is necessary.)

If we want to answer these demands, we shall have to find a new concept for the course of studies at least in the Master program. Whether we shall have to give them new names, as for example economical mathematics or technomathematics will be a question of politics or psychology in the university. The danger is not that such a course of study will become to narrow, rather the danger is in that the labels used to describe such studies do not give an accurate impression of their contents.

The question is: What should a Master program in techno-mathematics, which is already established at the Universities of Darmstadt, Kaiserslautern and Karlsruhe, be like? The area of application is continued after the undergraduate studies; it is either physics or another technical subject and takes 30% of the time. Data processing - I prefer this name to computer science, since it stresses more the role of the user - takes another 20%; during the undergraduate studies in Germany a student only learns at most one programming language. The main feature of the course of study is a reasonable project which incorporates the remaining 50% of the mathematical part with a field of application in interdisciplinary courses. It is of little use to merely set up courses as finite elements, calculus of variations, stochastic processes, system theory, reliability - the spirit of the program is the important thing. In my opinion a student should also have the experience of some lectures and maybe a seminar in pure mathematics, (i.e., in mathematics which is not applicable, only "beautiful"). He should feel the "homo ludens" character of mathematics, this "contemplative free play of the spirit", for creativity springs from the cooperation of the *homo faber* with the *homo ludens*. And creativity is needed to construct new models and to develop new methods of evaluation. But: This game can only be a small part, otherwise the student becomes a player and as a player, he can survive if he is inmensely high above the average or he has to find a Maecenas. Of 30.000 students in mathematics one will find less than 1% who will be able to do so. The rest of them have to earn their living by it. And by the way: the homo faber aspect is not all that uninteresting.

I shall demonstrate what I understand by the "spirit" with an example of an undergraduate seminar for technomathematicians at the University of Kaiserslautern. The topic in question is "linkages" - in its most simple case we have a "movement of cranks and gears". If you imagine a somewhat more complicated system of bars in the space, you can see the connection with framework construction. Questions on the kind of linkages and on their dimensions in order to find a desired output curve from a given input curve as accurately as possible, or questions on the stability of the framework itself, lead to quite different mathematical fields and ask for mathematics of extraordinary breadth and richness of ideas. First of all, there is the theory of motions in the plane and space as a basis of theoretical kinematics. In the plane, linkages are often described by complex numbers, in space, by quaternions. Questions on the stiffness or rigidity of the framework lead us into the field of the geometry of convex polyhedrons. By the way this is the field of "Lost Mathematics" which is described by Branco Grünbaum and it also has connections to the science of mineralogy. There are quite a lot of "wrong" theorems in the text books for engineering students and it is fun for a student of the 2nd year to see how these mistakes arise from incorrect definitions and vague presentations. Chebychev had originally developed his approximation theory for exactly this question of linkages. If several crank-movements are connected in series one gets problems in dynamical programming and eventually control theory. And at least all output curves of a crank-movement are algebraic curves. The transition from a crank-shaft to a throttle crank by changing the parametersis a catastrophe in the sense of algebraic geometry. How much this helps for an analysis or synthesis of linkages I do not know. To make a project study course of this would be too much. But to go into depth here and there while studying more examples of this variety of mathematical methods seems to be desirable.

Another point is the Master Thesis, which every techno-mathematician is supposed to write in connection with some practical experience in industry.(This has not to be fixed in the test requirements if all colleagues are of the same opinion) There is no need to be anxious about coming into contact with industry: A subject is discussed and considered together with representatives of the firm. Then we prepare the student for about six months by advising him to read the literature in connection with his subject. After that, he is sent to the research and development department for 3 to 6 months in order to be able to work at his problem together with engineers there. (There is no problem at all for such students in finding a job with a small salary.) He finishes his Master Thesis at the university. This procedure motivates the student, is highly regarded by industry, and helps to establish a "market" for mathematicians as I mentioned above. This may be a sufficient description of a possible therapy.

More experience in this way of education can be found at Oxford and Claremont (compare the papers by A. Tayler and J. Spanier). The Grandes Écoles in France have got the oldest tradition in this direction (compare the paper of A. Kempf). (The papers by A. Tayler, J. Spanier and A. Kempf appear in the proceedings of the Oberwolfach Conference "Math. in Industry".

Let me give a short review:

Mathematics is more useful than we and others have thought. Useful mathematics is more beautiful and more interesting than we have previously believed.

We are not dependent on any Maecenas who could cut off our financial support in hard times,because we are not living in an

Ivory Tower: Our students are important for the well-being of this society and it does not matter whether you look at this fact from the conservative or the alternative point of view. It is our task to realize this.

Of course to develop a new concept of a course in mathematics is only one aspect of the cooperation between the university and industry in the field of mathematics. One has to add *cooperative research* and the task of *continuing education*.

All this together creates a new, interesting, and comprehensive task for the university.

Goethe, were he alive today, could no longer write as he did in 1829 in a letter to Zelter: "I am afraid I shall never experience the day when a mathematician comes to a perception of nature by means of the bewitched maze of his formulas and uses his wits independently as any sane human being."

A REPORT OF THE "KAISERSLAUTERER MODELLVERSUCH": CONTINUING MATHEMATICAL EDUCATION

M. Schulz-Reese, Kaiserslautern

1 The starting-point

In Germany, the role of the universities in continuing education has been extensively discussed in the last few years. About eight years ago, in 1976, the universities received the commission to offer continuing education courses with the passage of the "Hochschulrahmengesetz", and, in the meantime, a trial plan for continuing education as an integral part of the university curriculum has been tested. At present, continuing education at German universities is still in the inception stage, but the problems of course organization and curriculum development are becoming quite clear. The potential demand for continuing education curricula at the universities by industry motivates further review and discussion of these problems, and, in this report, we restrict our analysis to the "Kaiserslautern trial project", the only project examining continuing education in mathematics.

The aim of our project was

- to become acquainted with the demand for continuing mathematical education, particularly, in the research and development departments of industry;
- to develop continuing education courses in close cooperation with industry;
- to arrange these courses;
- and to find out and analyse the repercussions of this project for mathematical research and university education.

2 The realization of the project

The project started in January 1981. First we wrote about 35 letters to firms from the chemical, electrotechnical, mechanical engineering and automobile industries, in which we introduced our ideas and asked for cooperation. Thirty-one companies answered; two of them saw no demand for continuing mathematical education and the rest took an active interest in cooperation. During the next few months we contacted altogether 20 research and development departments of these firms (which included, for example, Daimler-Benz, Ford, Opel, Siemens etc.). During the course of this investigation we wanted to find out:

- Is there a demand for continuing mathematical education?
- Which specific mathematical contents should be treated?
- In which form should continuing mathematical education be organized?

The demand for continuing education

There is indeed a demand for continuing mathematical education. This demand is, among other reasons, surely a consequence of the increased use of computers in all parts of industry. At present, experimental methods for problem solving are becoming more and more replaced by mathematical methods, and hence the demand for numerical methods suitable for implementation on a computer is growing enormously. At the moment, industrial companies have two possibilities of coping with this demand: Either they develop their own computer programs and need therefore co-workers with profound knowledge in modern numerical methods, or they buy or rent programs from software companies. In the second case - and this seems to be the more frequent case - the programs are often employed without knowledge of the underlying mathematical methods. They are used as "black boxes". In addition, the enormous capacity of modern computers leads to an excessive belief in computers; and, in connection with this, the ability and the willingness to use simpler mathematical methods decrease. The necessity of continuing mathematical education is obvious.

The function of continuing education

One important function of this kind of education should be to make "black boxes" more transparent, i.e. to impart the mathematical background of the underlying algorithms, to provide criterions for the efficient application of the programs, and to contribute to a critical use in practice. In addition, it is necessary to provide relatively elementary methods in close relation with concrete practical problems, i.e. to teach how to produce simple mathematical models for technical problems and to evaluate them with relatively simple mathematical methods. We think, therefore, that a continuing mathematical education program at any university should address the following two tasks:

- imparting new and relevant mathematical methods or
- regenerating and updating basic mathematical knowledge.

It is clear that industry mainly expects functional skills of its employees. But this cannot and should not be the only aim of our courses. Besides imparting and updating the functional skills our courses have to include something which we call an "educational component". This implies an intensification of the mathematical insight, an extension of the mathematical horizon. This includes, for example, the perception that totally different technical problems lead to similar mathematical models from which ideas and suggestions can be developed. And last, but not least, the engagement with mathematics can be fun and be enjoyed!

The contents of continuing education

Naturally, the required mathematics is dependent on the specific kind of industry. The entire spectrum of such a program includes courses from almost all branches of mathematics. For example, courses in the following fields should be included in the curriculum:

- Numerical methods in linear algebra, especially the solution of large systems of linear equations,
- optimization methods,
- integral transforms,
- statistics, probability theory and stochastic processes,
- differential equations,
- approximation and interpolation of functions,
- mathematical modelling.

In our project we have treated four areas:

A. Non-linear optimization

with topics:

- one dimensional search,
- algorithms without derivates (e.g. evolutionmethods),
- algorithms of first and second order (e.g. gradient-methods or conjugate-direction-methods),
- higher dimensional optimization with or without secondary conditions,
- problems of global optimization.

B. Numerical methods of linear algebra

with the topics:

- matrices and systems of linear equations,
- algorithms for numerical solution of large and sparse linear systems,
- matrix eigenvalue problems.

C. Methods of finite differences and finite elements

with the topics:

- boundary value problems of elliptic differential equations,
- numerical solution of linear boundary value problems by finite differences,
- construction of finite elements,
- finite differences and elements for quasilinear problems,
- modern algorithms for the solution of large systems.

D. Fourier transform

with the topics:

- the concept of distributions and Fourier transform,
- time- and frequency-domain correlations through Fourier-analysis,
- modern forms of the sampling theorem,
- discrete Fourier transform
- modern algorithms of the fast Fourier transform.

We are presently preparing an additional course, "Stochastic Processes in Linear System Theory".

For the development of our courses, it turned out that there was more to do than to combine and arrange available mathematical results. In particular, we have had to do our own research work on an unexpectedly large scale, since traditional mathematical research at universities has scarcely taken the requirements of industry into account.

The organization of continuing education

Another important question we had to investigate was how to organize and arrange continuing education courses. The vast majority of our collaborators from industry voted for seminars of about one week in length. Continuing education through correspondance courses, on which the participants should work in their free time, was thought to have few chances. However, there is much interest in well organized, written material. It is clear and was emphasized by industry that a success of these courses depends largely on the didactic methods of presenting them. As the collaborators of this trial project as yet have had no special experience in the area of continuing education, it was incumbent on us to study the didactic methods for teaching adults and to apply these methods to our project. We have done this with the help of the "Department of Pedagogics" of our university. The development of the accompanying texts and the planning for the courses was done in cooperation with industry. In preparing the curriculum two different methods were tried. First,

- seminar courses.

  These were one week events, in which a combination of lectures, study exercises, team or group work and discussions were used. Before the course began each participant was sent a list of basic requirements. Detailed reference material was added to give the participants the chance to deepen his knowledge in the subject offered.

Courses in the above four areas were done in this way. Second,

- "mixed" form.

  This organizational form consisted of a two day introductional presentation, a three month interval phase during which the participants could, with the help of the accompanying texts, work on the offered courses. This was supported by weekly internal seminars in the firms. Again at the end of the course, there was a two day meeting for concluding remarks and suggestions for improvement.

The requirement for this form of course was that several participants from one firm took part. We offered such a course in "Parameter optimization". The participants came from the firms Daimler-Benz and Volkswagen.
Before the courses actually began, there was a weekend conference in Oberwolfach, in September 1982, for the purpose of discussing with representatives from industry concepts already developed and to obtain further ideas, recommendations and proposals. The actual courses began in January 1983.

3 Some results and consequences

We did an extensive evaluation of the courses based on questionaries that the participants filled out and on concluding discussions held at the end of each individual course. It is clear that the evaluation cannot be a solid empirical investigation, but there are definite tendencies with regard to our future work. I shall now summarize some important conclusions.

Concerning a suitable seminar form for continuing mathematical education, the following model can be constructed:

- Preparational phase
  The participants should, with the help of exercises and test questions, be introduced to and motivated for the course.
- Seminar phase
  Here our present concept should remain the same with perhaps only minor changes.
- After the course
  Using additional exercise problems and references concerning the course, the participants should deepen and widen their knowledge concerning important parts of the subject. This has to be taken into consideration in the preparation of the course reference material.
- Final meeting
  If the participants show interest, a short meeting could be

held to discuss any remaining problems and follow up on further perspectives.

Our courses consisted of a total of about 100 participants: 70% were engineers, the rest were mathematicians and physicists. Over 80% of them work in research and development departments of industrial firms. This is where our potential applicants will come from.
In general, the participation of the university in continuing education has been well received by industry. Especially in the field of mathematics the universities have the best facilities for instituting continuing education programs.

We now turn to discussing the implications of our project for university education and mathematical research. One important result of our questionaire on industry is that industrial mathematics is being done mainly by engineers, while the mathematicians work mostly as assistant computer scientists. A common opinion in industry is that it is easier to teach engineers mathematics than to teach mathematicians how to work with technical problems. One reason for this is definitely that the present mathematical instruction at most of the German universities does not qualify the students for such a role in industry. This education is hardly oriented towards such professional demands. A possibility for changing this situation is a new study course, "Technomathematik" introduced at the university of Kaiserslautern. The study program consists of three parts:
- a mathematics curriculum with increasing emphasis on applications during the course of study,
- technology such as mechanical or electrical engineering and
- data processing to help students to use computers for solving mathematical problems.

Other concrete starting points have already been made in our department: Mathematics students from Kaiserslautern are doing voluntary training in German industrial firms. The topical orientation of the student's Master of Science Thesis is profoundly influenced by his experiences in industry outside of the universities. During the winter semester 1982-83, a new course was introduced, in which industry brings problems to the university, held to discuss any remaining problems and follow up on further perspectives.

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- a mathematics curriculum with increasing emphasis on applications during the course of study,
- technology such as mechanical or electrical engineering and
- data processing to help students to use computers for solving mathematical problems.

Other concrete starting points have already been made in our department: Mathematics students from Kaiserslautern are doing voluntary training in German industrial firms. The topical orientation of the student's Master of Science Thesis is profoundly influenced by his experiences in industry outside of the universities. During the winter semester 1982-83, a new course was introduced, in which industry brings problems to the university, and, students, with the help of professors, formulate the appropriate mathematical models and solve them. Such a "problem seminar" is being offered this semester.

In all these experiments, the experience gained at Kaiserslautern by the means of the pilot project, the increasing familiarity with industrial needs, and the establishment of contacts with industry are indispensible in further developing our continuing education program. Also the research project in technical mathematics beginning now in Kaiserslautern and the meeting in Oberwolfach 1983 are direct consequences of our model project. Our earlier visits in industry indicated an interest for cooperation from the side of the companies which went well beyond the interest in continuing education.

4 The further concept

In conclusion, I shall summarize our overall concept as a whole. Our activities will be concentrated in the three domains:
- improvement of mathematical education in view of a better preparation of our students for working in industry,
- extension of the continuing mathematical education, and
- research cooperation with industry as a contribution to technology transfer.

The fundamental aim of continuing education is to impart to scientists working outside the university the ability to formulate and solve their mathematical problems in a more concise and more efficient way. The experience gained through continuing education will continue to influence and change the topics and forms of university education. An improvement of the scientific studies in this sense will certainly also be beneficial for industrial research. Finally, the cooperation in research will help the universities   find ways of modernizing and complementing their curricula in applied mathematics and to discover further necessary roles for continuing education. Because of the inherently close interplay between basic university education, research, and continuing education, it is our plan to approach these three components as a unity.

5 References

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ON ESTABLISHING CONTACTS WITH INDUSTRY

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The aim of the research project, "Technomathematik" sponsored by the Volkswagen Foundation, is to promote a collaboration in mathematics between industry and the universities. Toward this end, we felt that we should try two possible approaches:

- Technology transfer from the university to industry whereby the university makes a substantial contribution in solving problems arising in industrial practice. Such activity by the university would have repercussions on fundamental research in mathematics itself.
- Incorporating, in the general mathematical education of our students, familiarity with mathematical problems arising in industry. The hope is that such a familiarity can better the chances of the graduates in finding and pursuing a meaningful career. The student becomes acquainted with such mathematical problems by participation in a problem seminar where these problems are discussed and by working on a topic for his Master of Science Thesis (Diplomarbeit) directly motivated by problems from industry.

In this project, we need close contacts with industry. In order to create systematic and lasting contact, we wrote early in 1983 letters to over a hundred German firms inquiring about mathematical problems arising in practice. We shall summarize the results of our inquiry later in the following.

Since there is relatively little industry in Kaiserslautern itself, and also in the surrounding area, we decided to write firms everywhere in Germany, in particular, those with known and active research and development divisions. The choice of firms was more or less random. In these letters we outlined the goals of our project and requested a description of their mathematical problems, which have arisen in practice and which have not yet been solved (It was not necessary that these problems were rigorously formulated). A total of 103 German firms were sent letters. At least three letters were sent to each of these firms - one to management, one to the research and development division, and one to planning and organization. Whoever in these firms had participated in the continuing education program at Kaiserslautern (cf. the report by M. Schulz-Reese) also received a letter.

Of these 103 firms, 64 answered; of these 26 firms sent problems, 28 were interested, but had no proper mathematical problems at the moment. Ten firms did not want to pursue collaboration with us, however, four of these already had programs with universities. Of the firms that sent us problems, seven had earlier contacts with us because of the continuing education.

In table 1, we summarize our results. In each row from left to right are the numbers of those firms receiving letters, those sending us problems, those indicating interest (but having no mathematical problems at present), those indicating no interest, and those not responding. The results depend on the type of industry. The strongest response came from the automotive industry; but the electrical and electronic industries, as well as the mechanical engineering, chemistry, and aircraft industries, also indicated a strong interest in our program. From energy producing industry, steel industry, and oil industry there was little response. Under "miscellany" are grouped the construction industry, food production industry, postal, optical industries and professional associations, etc. Also here the interest was rather small.

The problems sent to us are roughly grouped in table 2 with respect to mathematical fields: ordinary and partial differential equations, optimization, stochastic analysis and other areas such as numerical integration, approximation theory, Fourier analysis, etc. We have entered those problems in the last column on the right whose mathematical background is not quite clear, as, for example, "improved computational methods for parts of a combustion engine". For such problems the firms invited us for extensive discussions.

Most of the problems we received belong to the areas of differential equations (ordinary and partial) and optimization theory. But on the whole, our problems touch every area of applied mathematics, as for example, approximation theory, applied complex variables, oscillation theory, harmonic analysis, graph theory, and linear algebra.

In the meantime, we have visited 15 firms and discussed their mathematical problems in detail. Our first cooperative research projects with industry got underway in October 1983 because of these visits.

In conclusion, we can say that our initial inquiry with industry produced results. Industry is indeed interested in cooperating with the mathematics department of the university. The problems sent to us encompass all areas of applied mathematics, but most of the problems involve questions in the fields of differential equations and optimization theory. The contacts we have established in the manner described in this report have led to several cooperative research projects with industry.

Table 1:

industry	total	problems	interest	no interest	no reply
electrical, electronic	15	5	2	1	7
mechanical engineering	14	4	5	3	2
chemistry, rubber	13	5	2	-	6
steel, foundry	11	-	3	2	6
automobile, motor car accessoiries	11	7	2	-	2
energy producing industry	8	1	3	1	3
aircraft, shipyard	7	3	4	-	-
oil	7	-	2	2	3
miscellany	17	1	5	1	10

Table 2:

industry	differential equations	optimization	stochastic	other areas	background not clear
electrical, electronic	3	5	-	3	1
mechanical engineering	1	-	1	1	5
chemistry, rubber	2	2	1	2	-
automobile, motor car accessoiries	7	5	1	10	11
aircraft, shipyard	1	1	2	2	1
remainder	-	-	1	1	1
	14	13	6	19	19

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Die Arbeitsgruppe Technomathematik hat es sich zur Aufgabe gemacht, neue Formen und Möglichkeiten einer Kooperation zwischen Universität und Industrie im Bereich der Mathematik zu erarbeiten und durchzuführen. Dabei beschäftigt sich die Arbeitsgruppe mit den folgenden Schwerpunkten:

EINBEZIEHUNG KONKRETER FRAGESTELLUNGEN AUS DER INDUSTRIE IN DIE MATHEMATISCHE FORSCHUNG.

Im Rahmen des von der VW-Stiftung geförderten Forschungsprojekts "Technomathematik" werden mathematische Probleme aus der industriellen Praxis in Form von Problemseminaren, Diplomarbeiten und Forschungsaufträgen bearbeitet. Als Beispiele für schon bearbeitete oder in Bearbeitung befindliche Probleme seien genannt

- die Optimierung von Kurbelgetrieben, Nocken und Felgen;
- die analytische und numerische Untersuchung spezieller strömungsdynamischer und akustischer Probleme;
- die Simulation stochastischer Prozesse in der Zuverlässigkeitsanalyse.

PRAXISORIENTIERTE GESTALTUNG DER MATHEMATISCHEN AUSBILDUNG IM HINBLICK AUF EINE BESSERE VORBEREITUNG DER ABSOLVENTEN AUF DIE BERUFSWIRKLICHKEIT.

Dies geschieht z.B. durch den Studiengang "Technomathematik"; die wesentlichen Lernziele sind dabei:

- Bildung mathematischer Modelle für technische Probleme,
- Kenntnis von mathematischen Methoden zur analytischen und numerischen Auswertung der Modelle,
- Beherrschung des Computers als Werkzeug,
- Kommunikationsfähigkeit mit Ingenieuren.

Auch in die Mathematikausbildung der Ingenieure sollen Modellbildung und moderne, insbesondere numerische und stochastische Methoden verstärkt integriert werden.

MATHEMATISCHE WEITERBILDUNG FÜR DEN PRAKTIKER.

Das aus dem "Modellversuch zur mathematischen Weiterbildung" hervorgegangene Konzept für eine mathematische Weiterbildung für Ingenieure, Naturwissenschaftler und Mathematiker wird weiterentwickelt und fortgesetzt. Die angebotenen Kurse dienen der

- Unterstützung bei der Bewältigung praktischer Probleme,
- Anpassung an den neuesten wissenschaftlichen Erkenntnisstand,
- Einordnung des praktisch-beruflichen Wissens in einen theoretisch-wissenschaftlichen Rahmen,
- Auffrischung von Hochschulwissen.

Die Arbeitsgruppe Technomathematik setzt sich aus Professoren und Mitarbeitern der Universität Kaiserslautern und einer Gruppe von Mathematikern an der Technischen Hochschule Darmstadt unter der Leitung von Prof. Dr. Törnig zusammen.