Organisation for Economic Co-operation and Development
Global Science Forum

Report on
Mathematics in Industry

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Contents

Executive Summary

Industrial innovation is increasingly based on the results and techniques of scientific research. That research, in turn, is both underpinned and driven by mathematics. Given the increasingly intimate connection between innovation, science, and mathematics, it is natural to inquire whether the interface between these three activities is functioning in an optimal way. Recognising this, the delegates to the Global Science Forum (GSF) of the Organization for Economic Co-operation and Development (OECD) agreed to sponsor an international consultation to assess the present state of this interface in the participating countries and to identify mechanisms for strengthening the connection between mathematics and industry. (The interaction between mathematics and other sciences was left for future consideration.)

A workshop on "Mathematics in Industry'' was held in Heidelberg, Germany, on March 22-24, 2007. The objectives of the workshop were to

(1) analyse the relationship between the mathematical sciences and industry in the participating countries;
(2) identify significant trends in research in the mathematical sciences in academia and the mathematical challenges faced by industry in the globalised economic environment, and to analyse the implications of the trends for the relationships between mathematical scientists in academia and industry;
(3) identify and analyse major challenges and opportunities for a mutually beneficial partnership between industry and academia; and
(4) formulate action-oriented practical recommendations for the main stakeholders: the community of mathematical scientists, participating industries, and governments.

This report summarises the deliberations, and presents the findings and recommendations of the workshop and of further consultations among the participants. The recommendations are addressed to the academic community, governmental and other funding agencies, and industry. They are designed to stimulate the interaction between mathematics and industry; to enhance the curriculum for students of mathematics; to improve the infrastructure for increased interactions, both in academia and in industry; and to strengthen coordination and cooperation at national and international levels.

1. Introduction

The governments of the OECD countries recognise that industrial innovation is increasingly based on the results and techniques of scientific research. This connection is especially strong in areas where innovation is contributing to the well-being of society, such as health, security, communications, and environmental stewardship. The search for new life-saving drugs, the development of high-performance materials, and the protection of sensitive ecosystems - all of these application-oriented activities, and many others, are strongly dependent on fundamental research, and that research is inextricably linked to mathematics. The remarkable development of the natural sciences and engineering since the Renaissance is a consequence of the fact that all nature's known laws can be expressed as mathematical equations. The manipulation of these equations is a pillar of modern science, guiding the design and interpretation of empirical observations and laboratory experiments. Given the increasingly intimate connections between innovation, science, and mathematics, it is natural to inquire whether the interface between these three activities is functioning in an optimal way. One cannot take for granted that this is so, because each activity has evolved semi-independently, with its own traditions, communities, career paths, best practices, and vocabularies.

The delegates to the OECD Global Science Forum, who are senior science policy officials of OECD member and observer countries, following an initiative from the Delegation of Germany, agreed to sponsor an international consultation to assess the present state links between mathematics and industry in the participating countries, and to identify mechanisms for strengthening those links. They were strongly motivated to do so, because they represent national administrations that are deeply involved in funding and managing research (including research in mathematics), advancing industrial competitiveness and innovation, and promoting education at all levels. Accordingly, a workshop was held in Heidelberg, Germany, on March 22-24, 2007. The workshop brought together 54 experts from industry, academia, and government agencies, and was chaired by Professor Willi Jäger (Interdisciplinary Centre for Scientific Computing, University of Heidelberg).

This report summarises the deliberations and presents the findings and recommendations of the workshop and follow-on consultations among the participants. The recommendations are addressed to the academic community, governmental and other funding agencies, and industry. They are designed to stimulate the interaction between mathematics and industry; to enhance curricula for students of mathematics; to improve the infrastructure for increased interactions, both in academia and in industry; and to strengthen coordination and cooperation at national and international levels.

1.1 Objectives

The objectives of the workshop and report were fourfold:

1. Analyse the relationship between the mathematical sciences and industry in the participating countries;
2. Identify the most significant trends in research in the mathematical sciences in academia and the mathematical challenges faced by industry in the globalised economic environment, and to analyse the implications of the trends for the relationships between mathematical scientists in academia and industry;
3. Identify and analyse major challenges and opportunities for a mutually beneficial partnership between industry and academia;
4. Formulate action-oriented practical recommendations for the main stakeholders: the community of mathematical scientists, participating industries, and governments.

These objectives were achieved by

- surveying a broad sample of applications of mathematics in various industries at national and international levels;
- identifying future needs and opportunities for mathematics in industry;
- identifying the corresponding areas of research in the mathematical sciences;
- recommending desirable changes in education and training;
- proposing structural changes in the interface between mathematics and industry, and
- identifying useful new programs and initiatives.

1.2 Scope, Terminology

Mathematics as a scientific discipline has undergone major developments in scope, techniques, and results during the past century, as a result of both internal and external forces. It has become fundamental not only for industry but also for quantitative research in general, both basic and applied. This workshop focused in particular on the relationship between mathematics and industry and on the impact of mathematics on innovation in general. The relationship between mathematics and other *sciences*, although acknowledged as important and mutually beneficial, was left for future consideration, possibly under the aegis of the Global Science Forum.

In the discussions at the workshop, the term *industry* was broadly interpreted as any activity of economic or social value, including the service industry, regardless of whether it is in the public or private sector; *mathematics* (or *the mathematical sciences,* the two terms are used interchangeably) comprises any activity in the mathematical sciences, including mathematical statistics.

> "The exploding importance of information to all sectors of society and the pervasive role of technology in maintaining the security and prosperity of the nation have placed the mathematical sciences in a position of central importance. Mathematics provides the context for communication and discovery in many other disciplines."
>
> U.S. National Science Foundation, Panel Report (1998)

2. Perspective from Industry

From the point of view of industry, mathematics is an enabling technology. It provides a logically coherent framework and a universal language for the analysis, optimization, and control of industrial processes. Because it is an enabling technology, its contributions are rarely visible in the final product that industry delivers. Nevertheless, the economic impact is real, and many companies – old, as well as new – have achieved a competitive advantage through the judicious use of mathematics.

While mathematics presents industry in the 21st century with major opportunities, it faces significant structural challenges in the industrial environment. A strong pressure to organise research and development around well-defined projects, combined with an increasing trend to outsourcing, has led even large companies to significantly reduce their investment in the mathematical sciences. Because project-oriented workflows tend to rely more on established practices than on innovative enabling technologies, the role of mathematics research that might overcome or alleviate technical problems has been diminished, resulting in short-term vision and a loss in economic potential. Nonetheless, strongly innovative companies that properly exploit mathematics can rapidly gain a commercial edge over their competitors. This is illustrated dramatically by the success of start-up companies selling custom-designed software.

> "Mathematics offers business a formula for success"
>
> [Mathematicians] have come up with an impressive multiplication formula for British commerce and industry: spend a few million pounds promoting the use of maths as a strategic tool, and add billions of pounds of value to businesses. That is the thinking about a new government-industry consortium, the Mathematics Knowledge Transfer Network. The network aims to boost the use of maths throughout the economy from grocery distribution to banking, telecoms to manufacturing.
>
> Financial Times, February 2006

The claim of the present report is that the time has come to reinvigorate the synergy of mathematics and industry. Industry faces new challenges; mathematicians are ready to respond and can make significant contributions.

- Engineering systems and manufacturing processes are becoming increasingly complex; design optimization, time-to-market, and cost effectiveness have become major concerns.

- The ubiquity of powerful microprocessors and the advent of inexpensive data storage have led to an ever-expanding capability to collect data. But the useful integration of such data in an industrial context requires that they be processed, preferably in real time, and transformed into information and knowledge.

- Mathematical concepts and methods play a growing role for biotechnology and medical technology. An avalanche of data and information at molecular and cellular levels has launched a technological revolution. Better quantitative understanding of biochemical and biophysical processes is initiating innovative technologies producing drugs, biological materials or artificial tissues. Mathematical tools enable the design of new compounds and processes with prescribed functional properties.

- Societal concerns have led to regulatory actions that reflect more stringent requirements for the safety and reliability of products; they demand new methods for validation, verification, and the quantification of uncertainties.

- Globalisation, awareness of resource limitations, increasing sensitivity to anthropogenic effects on the environment, and general concerns about sustainability impose constraints on industry, as well as on society as a whole. They force industry to continually analyse and evaluate its activities in a broader social context, beyond the bottom line.

The traditional reductionist methods of the physical sciences and engineering are no longer adequate to answer many of the questions raised in an industrial environment. Today's problems are complex and nonlinear, they involve phenomena on multiple length and time scales, and their analysis can extend well beyond the realm of textbook mathematics. Industry requires access to qualified mathematical scientists who appreciate and understand its needs, who have been trained to capture the essence of an industrial problem in mathematical terms, who can apply methods of contemporary mathematics, and who are familiar with the latest advances in scientific computing and numerical algorithms. Only such people can produce the transformative new ideas that drive future innovations.

2.1 Common Themes

At the workshop, representatives from various industries described problems they face, often on a day-to-day basis, in developing competitive products, processes, and services for a demanding global marketplace. While the problems varied in details and from one industry to another, several common themes emerged.

- Complexity

Large-scale industrial problems are often modelled as large systems or networks of interacting objects. The objects themselves may be networks describing the technological, economical, financial, and social aspects of the problem, or they may represent components or steps of a technical process. The analysis of the behaviour and evolution of such systems or networks poses formidable challenges to industrial managers and decision makers. Even when the dynamics of the individual components are understood, the (nonlinear) interactions among the components make it inherently difficult to predict, let alone control, the evolution of the system as a whole.

> Complex Systems
>
> The interaction of objects obeying simple rules can produce remarkably complex and yet organized behavior. Electrons interacting with each other and their host lattice in a solid can give rise to magnetism and superconductivity. Chemical constituents interacting in solution can give rise to complex pattern formation and growth. Birds flying in the sky give rise to flocking behavior. Some of these behaviors, and their relation to the underlying microscopic laws, are now understood, but many of the most interesting and important cases remain mysteries. Learning how to understand and control these emergent behavior patterns will provide the foundation upon which to build complex systems.
>
> "Complex Systems. Science for the 21st Century."
> A U.S. Department of Energy, Office of Science Workshop (1999)

- Uncertainty

Uncertainty is an inherent feature of many industrial problems. Relations among individual components of a system are sometimes imperfectly understood, cause and effect cannot always be determined with certainty, and the only data available may be incomplete or subject to experimental error. The need to consider the human interface and the mandate to account for environmental and social considerations can add further uncertainty.

- Multiple Scales

Industrial problems do not usually play out on one length or time scale. For example, the macroscopic behaviour of a material depends on the interactions of atoms and molecules, and details about the latter are increasingly necessary to better understand the former. Also, the long-term dynamics of a complex system may depend critically on the details of what happens to the individual components on a much shorter time scale.

- Large-Scale Simulations

Computational science and engineering have become integral elements of the industrial design process. Large-scale numerical simulations are replacing experiments where the latter have become too expensive or even impossible. The aircraft industry provides a striking illustration of this phenomenon. While off-the-shelf software was often adequate for the computational solution of most of yesterday's problems across the industrial spectrum, simulations today require specialized numerical algorithms and sophisticated software management tools; without these, the simulations will be unable to keep pace with modern industrial demand.

> Nonlinearity
>
> Understanding nonlinearity is a central challenge for modern science. This is a huge task, since there are many sources and many sorts of nonlinearity. Sometimes its origin is the behavior being modeled: physical examples include combustion, phase transformation, and turbulence; biological examples include protein folding and excitable tissues, such as heart muscle and the nervous system. Nonlinearity can also come from other, more structural sources such as feedback or geometry: examples include the optimization of financial decisions; the pinch-off of fluid droplets; and the motion of surfaces under curvature-driven flows.
>
> "Opportunities for the Mathematical Sciences." A U.S. National Science Foundation, Division of Mathematical Sciences Workshop (2000)

- Data and Information

The ubiquity of networked computers, sensors, communication modules, and monitoring devices yields an ever-increasing stream of data. Not only does the quantity of data increase, but also the way the data is obtained, often from multiple sources and with varying degrees of precision. Integrating so-called multimodal data is already a formidable challenge, which is compounded if one is concerned about rare events, as in national security and economic activities. While classical statistical techniques work well as long as the number of variables is small, sampling techniques for high-dimensional data sets are still not fully developed. The recent popularity of search engines such as Google is due in large part to the development of novel mathematical ways to extract information from high-dimensional data sets.

- Interdisciplinary Teamwork

The successful solution of industrial problems requires the collaboration of experts from diverse disciplines. It is generally recognized by industry that mathematics is the *lingua franca* of science and engineering, and many industries include mathematicians in industrial research teams. However, not all mathematicians have the right skills to collaborate in an industrial environment, and not all industries appreciate the long-term approach favoured by mathematicians. Industry and academia have to engage each other in new ways that encourage innovation through interdisciplinary teamwork.

- Transfer of Mathematical Knowledge

Mathematics has gone through a period of intense growth and excitement, and the mathematical research community has developed a host of techniques that could be of significant benefit to industry and thus to society as a whole. Translating these techniques into practical terms and implementing them in applicable paradigms is, however, not straightforward. Some positive experiences and useful mechanisms for achieving this are outlined in this report.

2.2 A Case for Modelling and Simulations

The near-universal requirement for mathematical modelling and simulation deserves special attention. Mathematical models provide the theoretical framework for a quantitative understanding of industrial processes. Results of numerical simulations can be tested with experimental data, and discrepancies resolved by improving the mathematical model. In many concrete cases, mathematical modelling and simulation have revealed unexpected behaviour of the relevant system, and *in silico* studies have allowed predictions under conditions never tested experimentally. For example, the efficiency of modern search engines and the valuation of multi-dimensional financial derivatives would not have been achieved without innovative mathematical modelling and creative algorithm design.

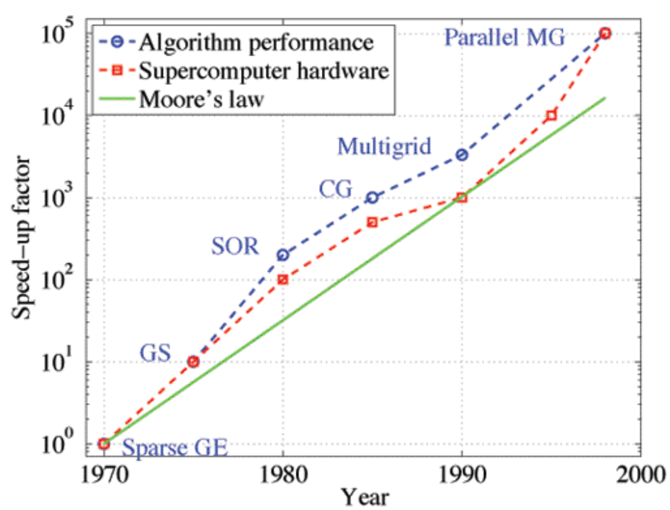

Figure 1. “Effective” speed increases from faster Supercomputer hardware (dashed line, red) and improved algorithms (dashed line, blue). The green line represents speed up according to Moore’s law (see D. Monroe, "Perfecting the languages and tools of science", SciDAC Review, pp. 50-61, Springer 2006.)

The integration of mathematics in large-scale numerical simulations has led to some spectacular successes in science, as illustrated in Figure 1. The phenomenal growth in computer hardware performance over the past 40 years, expressed succinctly in Moore's law, has been accompanied by an equally impressive improvement of the computational algorithms that underlie the numerical simulations. The type of progress shown in Figure 1 has been observed in some of the "classical" industries participating in the present study, such as the aircraft and petrochemical industries. In many instances, the improvements in the numerical algorithms have come from mathematicians who were interested in or motivated by industrial problems of the type described in the preceding paragraphs. Certainly not all industrial problems require the application of the most sophisticated mathematical techniques. But experience has shown that innovative mathematical modelling can lead to direct economic benefit, even in the smallest enterprises.

Perhaps the greatest challenge for modelling and simulation in industry comes when the need arises to incorporate knowledge from the social and behavioural sciences. Social factors play an increasingly important role in economic, financial, and technological decision making, in areas ranging from transport to communications, energy supply, and public health. Researchers in these areas have developed models of what they call *agent-based systems*, in which large numbers of independent agents interact, and collective behaviour emerges even in the absence of external forces.

3. Perspective from Academia

From the point of view of academia, mathematics is an independent discipline. It follows its own course; new ideas develop either independently within the discipline or under the stimulus of applications. Thus, strengthening the ties between mathematics and industry will stimulate research across the mathematical sciences, even as it enhances industrial innovation and competitiveness.

3.1 Mathematics Stimulated by Industrial Problems

The mathematical sciences are going through a period of intense intellectual growth. Spectacular developments are being reported in all areas of mathematics and statistics, be they continuous or discrete, deterministic or probabilistic. Unexpected connections have emerged between seemingly disjoint areas of the disciplines. Most of these developments have taken place in academia, driven by intellectual curiosity within the communities of mathematicians and statisticians. However, the workshop presentations highlighted several industrial problem areas that have had a significant impact on these developments as well (see programme in Appendix A).

- Chemical Industry

Many chemical reactions involve phase transitions and multiphase flows. The corresponding mathematical models contain nonlinear reaction-diffusion equations where the boundaries separating the different phases are unknown and must be found as part of the solution. These problems have motivated numerous analytical studies of free-boundary problems for partial differential equations and have led to new developments in geometric measure theory.

- Oil Exploration

All of our knowledge of the Earth's interior is indirectly derived from measurements. Among the most widely used techniques in oil exploration is reflection seismology, where elastic waves are sent into the Earth's subsurface and the reflection pattern is analyzed to gain information about the underlying structure. This is a classical "inverse problem": to derive the physical properties of the Earth's crust given a set of data collected in a seismogram. The computed results are usually not unique (more than one model adequately fits the data), and small changes in (even very accurate) data may correspond to large changes in the properties being estimated. The investigation of inverse problems has led to important developments in the analysis of "ill-posed problems" and the quantification of uncertainties.

- Medical Imaging

All medical imaging technologies, such as CAT scans and MRI techniques, use indirect inference to gain real-time information about the human body. A particularly promising technique currently under investigation is magneto-encephalography (MEG), measuring the extracranial magnetic fields produced by neuronal activity within a living brain. The structures and functions (including, crucially, diseases) of the brain can be studied through MEG source localization. The technique leads to interesting research in computational geometry and inverse problems.

- Microelectronics, Nanoelectronics

Progress in chip technology is intimately correlated with advances in the computational simulation of ever-larger networks of basic elements, such as transistors, capacitors, and resistors.

The dynamics of these basic elements are described by differential equations and are subject to algebraic side-conditions that are imposed by the network connectivity. The need for reliable circuit-simulation tools has been a strong motivation for the study of systems of differential-algebraic equations. Design and fabrication of nano-structured materials will require improved control and understanding properties at the nanometer scale. Quantum mechanical effects become important at the nano-scale and demand new mathematical and computational multi-scale methods.

- Logistics, Transportation

Problems of routing and optimal use of resources can be formulated as processes on networks, which, in real life, are often huge and random. Mixed discrete-continuous optimization for processes on such networks poses continuing challenges for mathematical theory.

- Finance

The theory of stochastic differential equations and the theory of martingales received a significant boost from the discovery of the Black-Scholes equation and its generalizations for modelling the prices of stock options and commodities. Risk analysis has similarly stimulated "extreme event theory", discrete mathematics, and game theory. The high dimensional systems arising in financial and economical problems are posing new challenges to numerical and computational research.

- Information Security

Information security covers a wide range of problems ranging from coding theory and cryptology to protocols for authentication, integrity, time-stamping, availability of service, and protection of intellectual property. The increased demand for information and communication security has led to exciting developments in algebraic geometry and cryptography.

- Communications

Popular means of communication such as cell phones require increasing bandwidth and robust transmission modes in media that are subject to random fluctuations. How to optimally package information and schedule switching are current topics of intense research in mathematics, statistics, and computer science.

- Entertainment

The fidelity of MP3 audio compression and the quasi-reality of movies such as *Jurassic Park* and *Harry Potter* rely on the use of sophisticated, recently invented, mathematical algorithms for data compression and image processing. The fundamental concepts of these techniques originated in mathematics, and their applications have in turn influenced the development of novel ideas in harmonic analysis.

The above are but a few examples to show that mathematical problems arising in industry merit the attention of the academic community. Not only does their solution contribute to the economic health of industry, but also they can provide fresh avenues for new and exciting developments in the mathematical sciences. Further areas were discussed during the workshop (see programme in Appendix B).

3.2 The Academic Environment

The academic discipline of mathematics has undergone intense intellectual growth, but its applications to industrial problems have not undergone a similar expansion. Mathematical problems arising in industry are still commonly identified with a few classical topics in mathematics - for example, numerical computations, statistics, and combinatorial optimization - yet the impact these problems could have on the discipline is not always fully appreciated. The organizational structure of academia, with more or less autonomous departments, runs counter to the idea of inter-disciplinarity; and cross-disciplinary collaborations are the exception rather than the rule. Other impediments to the interaction of mathematics and industry are the academic award system, which does not always take into account the contributions mathematicians make to disciplines outside their immediate department, and the curriculum, which does not offer many opportunities for students to become familiar with industrial applications.

"Pure" and "Applied" Mathematics

Mathematical scientists are commonly classified as being either "pure'' or "applied.'' Pure mathematicians supposedly follow natural paths of inquiry toward the development of new concepts and new theories within the discipline; applied mathematicians are the ones who use mathematical techniques to address problems arising outside the discipline. The distinction is vague, misleading, and useful at best for classification purposes. The vigor and vitality of the discipline depend critically on a strong connection between the creators and users of mathematics. Excellent mathematics, however abstract, leads to practical applications. In turn, hard problems in nature stimulate the invention of new mathematics.

The challenges that have arisen in industry require innovations in mathematical theory and methodology. Mathematics provides the universal language to address common issues for classes of problems, and its results are portable to a variety of application areas. Specific industrial projects provide excellent test cases that can produce guidelines for the development of new mathematical tools, the evaluation of mathematical models, and the design of computational methods. As industrial R&D becomes increasingly tied to specific projects, adjusted to the demands of the market, and subject to considerations of profit and intellectual property, it is important that industry maintain its ties with the academic research community. On the other hand, while freedom of academic research is essential, mathematics and mathematicians must recognize the importance of industrial problems for the development of their discipline and should adjust the academic curriculum to the new environment.

4. Mathematics and Industry - A Partnership

The interface between mathematics and industry is much more than a medium for technology transfer. The vision that underlies this report is for a synergetic partnership, where information is exchanged freely at the pre-competitive stage, and knowledge is shared profitably by the mathematical and industrial communities.

A successful partnership requires a good fit between the expectations, the time scales, and the expertise of the partners. A project that is undertaken jointly must be properly structured, and the partners must share a reasonable expectation that the necessary mathematical techniques are available or at least can be developed.

The degree of penetration of mathematics in industry is in general unbalanced, with a disproportionate participation from large corporations and relatively little impact in small- and medium-sized enterprises. Considering that the latter constitute the majority of enterprises in most industrialized countries, mathematics clearly has a great opportunity to broaden its economic impact. The question is how to create acceptable mechanisms to stimulate the interaction of mathematics and industry and maximize the impact of the partnership. The discussions at the workshop indicated that different countries have developed different mechanisms depending on their state of development and economic structure.

In appendix A, there are references to specific projects, institutions and organisations, selected from the reports of the delegates. This list is not complete and does not imply an evaluation. Interested readers are invited to seek detailed information via the Internet.

4.1 Mechanisms

Although few patterns are discernible as yet, the workshop participants identified several mechanisms that can improve the partnership between mathematics and industry.

- Interdisciplinary Research Centres

Several countries have created "institutes" (bridging academia and industry) where mathematical scientists interact with industrial researchers to jointly address industrial problems. Some are based within individual universities, while others have been established to operate on a national or international scale. Their activities cover a broad range, from special workshops on topics of exceptional contemporary interest and potential impact, to long-term sponsorship of industrial postdoctoral researchers and collaboration in industrial projects.

- Faculty Positions for Industrial Mathematics

Some universities have created chairs, professorships, and adjunct professorships in Industrial Mathematics. These positions can nucleate collaborations, foster industrial problem solving in an academic environment and reshape academic curricula and postdoc activities to the needs of industry. They can provide opportunities for mathematicians who are successful in the academic world to pursue their interest in industrial problems. Adjunct professorships, joint positions in university and industry, offered to experts from industry, enable a direct and optimal transfer between industrial demands and academic research and education.

- Research Internships

Research internships are a mode of academic-industry interaction that has recently been taken up by a number of countries. An internship is a research project of short duration (typically 4-6 months) that is undertaken in collaboration with an industry partner and places a graduate student or postdoc part-time in the company. Experiences so far have been very positive, with outcomes ranging from technology transfer to publications and theses, while also fostering further collaborations in the form of additional internships and larger research projects.

- Special Interest Groups (SIG)

Professional societies and some government agencies sponsor special interest groups of various kinds. They provide an excellent forum for the exchange of ideas and best practices, and a framework for collaborative research.

Objectives of SIG:

- Stimulating mathematical research on challenging industrial problems;
- Encouraging joint projects between scientists and industry;
- Promoting mathematical models, numerical methods and scientific computing in industry.

Activities of SIG:

- Mathematical modelling, analysis and solution of problems arising in industry;
- Operation of workshops and symposia;
- Creating links between mathematicians and applied scientists, in industry and academia;
- Documentation of and information about existing research in specific fields.

- Direct Research Collaborations

In contrast to the well-established intensive cooperation between the industrial and academic research communities in, for example, the chemical and engineering sciences, no such tradition exists in the mathematical sciences. Corporate-academic cooperation in mathematical research is restricted mostly to large industries, such as financial engineering, insurance, and the information technology industry.

Personnel Exchange Partnerships

Exchange of personnel is probably the most effective vehicle for transferring research results among institutions and disciplines and converting them into products and markets. Graduate student and post-doctoral fellowship programs bring bright young people from universities into national laboratories and industry. Faculty exchanges bring industrial scientists and engineers into universities, while faculty members move into industry.

- Study Groups

In several countries, study groups have evolved that are tailored to the needs of industry and provide a forum for the discussion of open problems. These rely on brainstorming sessions in small groups of mathematical scientists and industrial researchers. Academic researchers then gravitate to those problems in which they are most interested, and report their findings at follow-up sessions. In large companies, in-house study groups can also enhance "open innovation" and "communities of practice".

The typical model is the following:

Research workers from industrial and commercial concerns are invited to present one of their current technical problems for study in working sessions with leading specialists from the academic community. Problems may come from a wide variety of subject areas, but should be amenable to mathematical modelling and analysis. In a week of brainstorming and mathematical modelling there is usually enough time to generate and assess many ideas for solving the problem, and usually some of the ideas are checked in more detail. The real research may only start afterwards, for which useful contacts are made with the academics to work together. In this way, study groups serve to establish links between university mathematics departments and industry.

- Student Activities

The experience with study groups has highlighted the need to educate mathematicians capable of meeting the demands for mathematical expertise in industry, and who can master complex problems that require multidisciplinary competence and knowledge of modern communication techniques. In particular, at the student level, the concept of "modelling weeks" has been proved to be invaluable in opening young researchers' eyes to the potential of mathematics in industry. These modelling weeks are microcosms of study groups, tailored to the needs of graduate students. They provide a counterweight to the enormous pressure on talented young researchers to follow traditional pathways to successful careers as academic mathematicians.

The typical structure is the following:

Students coming from different universities are organized in interdisciplinary and international teams, each of which is supposed to respond to a problem posed by an instructor (possibly a real industrial delegate). The educational aims are to simulate an industrial environment, working in heterogeneous groups; enhancing communication skills, with presentation of the results orally (and by a written report, prepared at home, in collaboration also via Internet).

- Translation of Technology

Mathematical technologies are portable to many areas in industry; however, problem mining and translation at the interface are needed to use them efficiently. A number of countries have set up programs or institutes where "technology translators" build relationships between industry and academia. Their aim is to promote the culture of using mathematics in industry, at both strategic and technical levels. They generally have academic experience to at least PhD level and have worked in industry, so they are able to communicate effectively to industrialists and academics at all levels. Technology translators identify industrial opportunities for mathematics, understand the detailed requirements of each company, translate problems into the language of mathematics, identify the best mechanisms and academics with relevant expertise, facilitate the relationships to ensure successful collaborations, and assist with the implementation and exploitation of the results. More information is available from the websites cited in Appendix A4.

- Consultancy

In some countries, consultancy has been adopted as the most direct path to promote the transfer of knowledge from academia to industry. Intermediary organizations enable this mechanism of knowledge exchange on a national or, in a few cases, transnational scale.

- Software Companies

Software companies can package mathematical ideas so that they can be applied by non-mathematicians. Encouraging such commercial exploitation of mathematics can produce substantial dividends for society.

- Transnational Cooperation

There exist examples of transnational cooperation both in industrial problem-solving and in coordinating industrial mathematics programs, exchanging teachers and students, and sharing and using information on best practices (both in collaboration with industry and in adapting the academic curriculum to using mathematics in industry).

4.2 Intellectual Property

Mathematical ideas and methods may be entities of high economical value. Therefore intellectual property (IP) is an important issue in industry-academic relations. Issues surrounding "mathematical IP" are distinct in the sense that mathematics is not a tangible product but rather a combination of the underlying mathematical equations along with their expression in algorithmic form. In cases where mathematical algorithms are implemented in computer software, mathematical IP issues may arise that are fraught with difficulties. However, because IP practices and processes vary greatly according to country, industry, and even academic institution, the workshop participants refrained from making any specific recommendations about the management of IP, except to point to the need to share best practices in the management of mathematical IP and to learn from successes and failures of scientists and organizations working at the interface of mathematics and industry. In particular, as mathematics in industry interfaces develop into partnerships, more creative and flexible ways should be developed for industrialists and investors to protect their interests.

5. Conclusions and Recommendations

Industry faces problems that extend well beyond the envelope of classical topics in mathematics. Many of these problems have a significant mathematical component, and the intellectual challenges they pose fall in many cases within topical areas of current research in the mathematical sciences. Stronger links between mathematics and industry will be beneficial both to the partners and to national economies. They will inspire new mathematics and enhance the competitive advantage of companies.

Several countries have developed a variety of mechanisms to facilitate a constructive relationship between mathematics and industry; in these countries, dynamic collaborations already exist. In others, there is an urgent need to create or revitalize the connection. Governments can play a role, notably through national funding agencies. This section of the report contains recommendations that can improve the interface. They have been suggested by the workshop participants and are addressed to the academic community, governmental and other funding agencies, and industry. The list reflects best practices and is meant to be indicative; it is by no means exhaustive, and not all recommendations may apply in particular situations.

5.1 Mathematics for Industrial Innovation

The workshop participants recommended several mechanisms to stimulate the interaction.

- Interdisciplinary Research Centres whose mission is to increase the impact of mathematics in industry by fostering research of a truly interdisciplinary nature, linking mathematics to important scientific and technological problems from industry;
- Special positions in Industrial Mathematics to stimulate cooperation with industry, to facilitate adaptation of academic structures and curricula, and to foster industrial cooperation and collaboration at the national and transnational levels;
- Workshops to identify mathematical problems in specific industries. These workshops should bring together experts from academia and industry and pave the way to collaboration;
- Workshops to highlight novel mathematical techniques relevant for industry, such as dynamics of complex networks, randomness and uncertainty, sampling in high-dimensional spaces, rare events, extracting information from large data sets, multiple scale problems, and algorithm design for advanced computing architectures.

5.2 Education and Training

A partnership between mathematics and industry, as envisaged by the workshop participants and proposed in the present report, requires adjustments of the curriculum for students of mathematics who are interested in and motivated by industrial problems. The adjustments should be considered with care. The curriculum should not become a “light” version of the accepted curriculum for future researchers, and the students will need to be familiar with the standard canon of the discipline. The workshop participants recommended several steps for consideration:

- Developing curriculum options that prepare the students for a career at the interface of mathematics and industry. Curricula should reflect the reality that such a career requires both a solid background in mathematics and the intellectual curiosity to go beyond mathematics. The curriculum should be flexible but subject to rigorous quality control. It should stress innovative applications of mathematics, highlight problems that are industry-driven, and encourage students to broaden their scientific interests. Above all, it should be designed to demonstrate that the interaction of mathematics and industry leads to exciting research opportunities and benefits.

- Creating opportunities for research participation at the undergraduate and graduate level. Early exposure whets the appetite, and provides hands-on experience. The mechanisms may include industrial internships, modelling camps, and summer schools.

- Establishing postdoctoral programs in conjunction with industry. Such programs offer a first-hand experience of working in an industrial environment and thus a realistic perspective on a career in industry, while preserving the option of an academic career.

- Setting up opportunities for secondary school teachers to participate in academic-industrial interactions. High-school students are often taught as if mathematics is a dead science and a finished product ready for applications. Giving teachers an opportunity to experience the excitement of research may enliven their view of the subject area.

- Sponsoring teams of junior researchers for industry-oriented research. Such teams are an excellent method for attracting talented young scientists to the field and for building a future generation of mathematicians interested in and capable of doing research in an industrial environment.

5.3 The Interface between Mathematics and Industry

The workshop participants identified several mechanisms and initiatives that could be established at the interface between mathematics and industry to promote a more systematic exchange of knowledge and of experts.

- Joint teams, virtual organizations or "collaboratories," to develop new mathematical technologies for targeted industries. Such teams, comprising experts from both sides, should be problem-oriented rather than project-oriented, and their mandate long-term rather than short-term.

- Positions for "translators" to enhance the process of communication between industry and the world of mathematics. The problems in industry are not obviously expressed in the language of mathematics, and this language itself has developed its own idioms and syntax.

- Web access to information about problems, methods, solutions, centres of excellence, and available expertise. Such information could be especially useful for small- and medium-sized enterprises.

- Networks of experts. Whether formal or informal, sponsored or independent, networks improve the likelihood of collaboration.

- Model agreements on intellectual property rights. The subject of IP is daunting, and a little advice and a more staged approach may go a long way to alleviating the fear of parties involved in negotiations.

5.4 Academic Infrastructure

The academic world is organized by departments, which are more or less independent. This structure is not optimal for the enhancement of interactions with industry, where a premium is put on teamwork and interdisciplinary activities. The workshop participants proffered several suggestions for improvement.

- A supportive environment for interdisciplinary activities. Students need to have the flexibility to explore career options outside academia. Faculty need encouragement to explore the opportunities for mathematics outside their immediate specialization.

- Appreciation and appropriate rewards for faculty involvement in outreach activities to industry. Brilliant research done in the proverbial ivory tower is necessary for the good of the discipline and its ability to contribute new ideas and techniques to science and industry, but outreach activities that improve the broader impact of mathematics are equally important for the health and image of the subject.

- Faculty positions for researchers from industry. Role models are important for students. Active researchers from industry offer real-life experience that is normally lacking among regular faculty in a mathematics department.

- Quality control of industrial mathematics projects. Mathematics for industry must meet accepted standards of rigour. At the same time, projects, once identified, need to be pursued with the vigour that industry demands.

5.5 Industrial Infrastructure

Industry can take several steps to attract the attention of young researchers and talented students to problems of interest.

- Industry can make its environment more attractive for qualified researchers if an acceptable compromise can be reached between the long time scale typical for mathematics research and the much shorter time scale typically faced by industry.

- Mathematicians, like all scientists, thrive on challenges, are naturally curious, and dislike routine work. Giving researchers in industry the opportunity to continue their education by attending conferences and workshops improves the image of a research career in industry and helps the researchers stay in touch with their discipline.

- Industry can enhance its presence in academia by actively supporting activities that potentially increase the impact of mathematics in industry. The creation of special chairs or faculty positions should be given careful consideration.

- Industry can make substantial intellectual contributions by actively participating in the activities of the various mathematical research institutes discussed in Section 4.1. An institute whose mission is to increase the impact of mathematics in industry can be the flagship of any partnership between mathematics and industry.

- Study groups dedicated to industry-oriented problems, summer schools dedicated to industry-oriented research in mathematics, and modelling camps for students, all benefit from participation by researchers from industry. Participation increases the likelihood that the programs stay focused and that their eventual outcome is of genuine industrial value.

5.6. National and International Coordination

Mathematics is a global enterprise. Research results are published in peer-reviewed journals that have international boards of editors; they are presented at international conferences or posted informally on the World Wide Web and made accessible to the community at large. International collaborations are the rule among leading researchers. It is important that this *modus operandi* be maintained in the context of mathematics and industry as well. The workshop participants noted that all recommendations presented so far should be viewed in the light of a global science activity.

Experience with study groups around the world has revealed many commonalities between industrial problems arising in different countries, thus highlighting the risk of undesirable duplication of effort on the part of the academic community and the consequent need for international coordination at several levels:

- International cooperation of funding agencies and governments;
- Exchange of effective practices at national and international meetings;
- International networks for research and education, possibly supported by suitable publishing resources and shared databases.

5.7 Action Items

The workshop participants recommend that an international task force be created to promote the initiatives outlined in this report, to evaluate and prioritize the recommendations with respect to their economic implications, and to identify the resources necessary for the implementation of the various recommendations. The task force should include representatives from academia, industry, and government, with additional expertise called on as necessary.

At the OECD/GSF level, the workshop participants recommend that the Global Science Forum foster the initiative and assist the framing of any follow-up activities.

Appendix A

References:

The following references provide information on relevant activities, centres, organizations and networks. The list is based on the contributions made during the Workshop. Therefore only institutions and activities in the participating countries are mentioned. The list is not meant to be complete.

A.1 Relevant Reports

Several committees, mainly in the United States, investigated the state and the role of Mathematics and its relation to Science and Technology. Most of the reports were produced prior to 2000. A more recent report (2005) on Computational Sciences also covers Mathematics.

The "David" Report
Renewing U.S. Mathematics: A Plan for the 1990s
National Academy Press, Washington (DC),1990
http://books.nap.edu/openbook.php?isbn=0309042283&page=R1

A Roadmap For Mathematics in European Industry
(MACSI-Net Mathematics, Computing and Simulation for Industry
A European funded network of Excellence (2000-2004))
http://www.macsinet.org/newsletter.htm#MARCH2004

PITAC Report 2005
Computational Science: Ensuring America's Competitiveness
http://www.nitrd.gov/pitac/reports/

SIAM (Society for Industrial and Applied Mathematics)
Report on Mathematics in Industry (1998)
(http://www.siam.org/about/mii/index.php)

National Science Foundation (NSF), United States:
Report of the Senior Assessment Panel for the International Assessment of the U.S. Mathematical Sciences (1998)
http://128.150.4.107/pubs/1998/nsf9895/nsf9895.pdf
Report: Mathematics and Science (1999)
http://128.150.4.107/pubs/2000/mps0001/mps0001.pdf
Opportunities for the Mathematical Sciences (2000)
http://128.150.4.107/pubs/2002/nsf0120/start.htm

A.2 Established Centres

The following centres are ordered alphabetically by country. Information about their founding principles, structure, programme and activities can be found via their homepages. These centres are based on a variety of different concepts. Their experience may help to optimize strategies for improving the links between mathematics and industry.

CSIRO (Commonwealth Scientific and Industrial Research Organisation)
http://www.csiro.au/org/ps6d.html (Australia)

RICAM (Radon Institute for Computational and Applied Mathematics) Austrian Academy of Sciences (Austria)
http://www.ricam.oeaw.ac.at/

SCOMA (Center for Scientific Computing and Optimization in Multidisciplinary Applications)
http://www.mit.jyu.fi/scoma/ (Finland)

CERFACS (European Centre for Research and Advanced Training in Scientific Computation)
http://www.cerfacs.fr/ (France)

INRIA Institut National de Recherche en Informatique et en Automatique
http://www.inria.fr/ (France)

ZIB (Konrad-Zuse-Center for Information Technology)
http://www.zib.de/ (Germany)

WIAS (Weierstraß-Institute for Applied Analysis and Stochastics)
http://www.wias-berlin.de/ (Germany)

MATHEON (DFG Centre "Mathematics for Key Technologies")
http://www.matheon.fu-berlin.de/ (Germany)

IWR (Interdisciplinary Center for Scientific Computing)
http://www.iwr.uni-heidelberg.de/ (Germany)

ADAMSS (Advanced Applied Mathematical and Statistical Sciences) (formerly MIRIAM)
http://www.mat.unimi.it/users/miriam/ (Italy)

MOX (Modelling and Scientific Computing)
http://mox.polimi.it/it/progetti/indexpro.php?en=en (Italy)

CASA (Centre for Analysis, Scientific computing and Applications)
http://www.win.tue.nl/casa/ (Netherlands)

CMA (Mathematics for Applications)
http://www.cma.uio.no/ (Norway)

ICM (Interdisciplinary Centre for Mathematical and Computational Modelling)
http://www.icm.edu.pl/eng/ (Poland)

CIMNE (International Center for Numerical Methods in Engineering)
http://www.cimne.upc.es (Spain)

OCIAM (The Oxford Centre for Industrial and Applied Mathematics)
http://www2.maths.ox.ac.uk/ociam/ (United Kingdom)

IMA (Institute for Mathematics and Its Applications)
http://www.ima.umn.edu/ (United States)

Mathematics Clinic (Harvey Mudd College, United States)
http://www.math.hmc.edu/clinic/ (United States)

IPAM (Institute for Pure and Applied Mathematics)
http://www.ipam.ucla.edu/default.aspx (United States)

SAMSI (Statistical and Applied Mathematical Sciences Institute)
http://www.samsi.info/ (United States)

DIMACS (Center for Discrete Mathematics and Theoretical Computer Science)
http://dimacs.rutgers.edu/ (United States)

NISS (National Institute of Statistical Science)
http://www.niss.org/index.html (United States)

A.3 Networks, Organizations

National and international co-operation through networks and organization is essential for improving the situation for research and education in Industrial Mathematics. Here, remarkable success can be reported. However, improvements are possible and necessary.

ECMI (European Consortium for Mathematics in Industry)
http://www.ecmi-indmath.org/

ECMI Special Interest Groups
http://www.ecmi-indmath.org/info/index.php

ECMI Educational Programmes
http://www.ecmi-indmath.org/edu/index.php

ESGI (International Study Groups for Mathematics in Industry)
http://www.math-in-industry.org/

ECCOMAS (European Community on Computational Methods in Applied Sciences)
http://www.cimne.com/eccomas/html/about.htm

KTN (Knowledge Transfer Network for Industrial Mathematics)
www.industrialmaths.net

"Mathematics in Industry", network sponsored by the German government http://www.mathematik-21.de/

MACSI (Mathematics Applications Consortium for Science and Industry)
http://www.macsi.ie/

MITACS (Mathematics of Information Technology and Complex Systems)
http://www.mitacs.math.ca/index.htm (Canada)

A.4 Translational Institutions

These institutions specialise in finding matches between industrial challenges and the expertise that exists in academia, thus overcoming the inherent differences between the academic and industrial worlds. The former specialises in developing general-purpose methods and tools, while the latter needs quick, practical and robust solutions for real-life problems.

IMCC (Industrial Mathematics Competence Center)
http://www.mathconsult.co.at/imcc/ (Austria)

ITWM Fraunhofer-Institut für Techno- und Wirtschaftsmathematik
http://www.itwm.fhg.de (Germany)

(Swedish dependence: Fraunhofer Chalmers Research Centre for Industrial Mathematics (**FCC**), Göteborg, first European joint venture of the Fraunhofer-Society)

IFIM (Institute for Industrial Mathematics)
http://ifim.uni-paderborn.de/ (Germany)

I2 T3 (Innovazione Industriale Tramite Trasferimento Tecnologico)
http://www.i2t3.unifi.it/ (Italy)

SINTEF-Applied Mathematics
http://www.sintef.no/content/page3____342.aspx (Norway)

Smith Institute for Industrial Mathematics and System Engineering
www.smithinst.co.uk (United Kingdom)

Appendix B

GLOBAL SCIENCE FORUM
MATHEMATICS IN INDUSTRY
Heidelberg, Germany, March 22 - 24, 2007
Workshop Program

Locations:
- Heidelberger Akademie der Wissenschaften, Karlstraße 4
- Print Media Academy, Kurfürsten-Anlage 52-60
- Kulturbräu, Leyergasse 6
- Haus Buhl, Hauptstraße 232/34

Thursday, March 22

Themes:
- Setting the Discussion
- State of the Art, Experiences in the Member States
- Print Media Industry - Presentation and Reception

14.00-14.30

Welcome, Information
- OECD: Dr. Michalowski (Paris)
- BMBF: Dr. Koepke (Bonn)
- Local Organizer: Prof. Jäger (Heidelberg)

14.30-15.00
- Mathematics-Industry: Experiences and Expectations
  Prof. Jeltsch (Zurich)
  Chair: Prof. Jäger (Heidelberg)

15.00-15.30
- Challenges to Mathematics in Print Media/Multimedia Technology and Production
  Prof. H. Kipphan (Heidelberger Druckmaschinen AG, Heidelberg)
  Chair: Prof. Jäger (Heidelberg)

15.40 -18.00
- Reports about the current situation in the Member States (main activities in transfer, funding, education, ...)
  Chair: Prof. Sprekels (Berlin)

18.10-18.30
- Experiences, observations and comments – Report of a mathematician in industry.
  Dr. Schuppert, (Bayer Technology Services, Leverkusen)
  Chair: Prof. Sprekels (Berlin)

Friday, March 23

Themes:

- Meeting the Partners
- Challenges to Mathematics
- Offers from Mathematics

9.00-9.30

- Chemical Industry
  Dr. Hahn (BASF, GERMANY),
  Chair: Prof. Bock (Heidelberg)

9.30-10.00

- Pharmaceutical Industry
  Dr. Rippmann, Prof. Neumann (Merck, GERMANY),
  Chair: Dr. Schuppert (Bayer, Leverkusen)

10.00-10.30

- Materials: Polymers
  Dr.ir. C.F.J. den Doelder (Dow Benelux B.V., NETHERLANDS)
  Chair: Prof. Schilders (Eindhoven)

11.00-11.30

- Aviation
  Dr. Adel Abbas (Airbus, SPAIN),
  Chair: Prof. Bonilla (Madrid)

11.30-12.00

- Micro-Nanotechnology
  Dr. Cremonesi (STMicroelectronics, ITALY)
  Chair: Prof. Capasso (Milano)

12.00-12.20

- Discussions

14.00-14.30

- Communication
  Dr. Kärkkäinen (Nokia Research Center, FINLAND),
  Chair: Prof. Gyllenberg (Helsinki)

14.30-15.00

- Energy
  Dr. John Reidar Granli (Statoil, NORWAY)
  Chair: Prof. Winther (Oslo)

15.00-15.30

- Transportation
  Dr. Jaeger (BVO Busverkehr Ostwestfalen GmbH, GERMANY),
  Chair: Prof. Grötschel (Berlin)

16.00-16.30

- Material Design
  Prof. Wimmer (Materials Design, FRANCE),
  Chair: Prof. Niezgodka (Warsaw)

16.30-17.00

- Financial Service Industry
  Prof. Nonnenmacher (DZ Bank, GERMANY)
  Chair: Prof. Jäger (Heidelberg)

17.00-17.45

- Steel Industry
  Dr. J. Nakagawa (Nippon Steel Corporation, JAPAN)
  Chair: Prof. M. Yamamoto (Tokyo)

Saturday, March 24

Themes:

- Analysis of the Situation
- Suggestions for Changes

9.00-10.45

- Discussion group
  Challenges to Research in Mathematical Sciences, Resources and Gaps in Mathematical Theory and Methods
  Chair: Prof. Capasso (Milano)

- Discussion group
  How to organize research, education, cooperation, and funding to promote transfer
  Chair: Prof. Bourguignon, Prof. Cioranescu (Paris)

11.50-12.20

- Formulation of the results
- Report of the subgroups

14.00-15.30

- Round table
  Plenary discussions of main aims in research, education, training, and cooperation, new structures in funding
  Chair: Professor Kaper (NSF, Washington)

15.30- 16.00

- Closing Remarks, Farewell
  Chair: Prof. Jäger (Heidelberg)

Reception at *Print Media Academy* as guests of Heidelberger Druckmaschinen AG (Heidelberg).

With a global market share for sheet fed offset printing machines of more than 40 percent, Heidelberger Druckmaschinen AG (Heidelberg) is the world's leading solution provider for commercial and industrial customers in the print media industry. Headquartered in Heidelberg, Germany, the company focuses on the entire process and value chain for popular format classes in the sheet fed offset and flexographic printing sectors.
To demonstrate his lecture on challenges to mathematics in print media industry, Prof. Kipphan, Senior Vice President for Advanced and Future Technologies, presented the impressive high technology in print media industry.

Appendix C

GLOBAL SCIENCE FORUM
MATHEMATICS IN INDUSTRY
Heidelberg, Germany, March 22 - 24, 2007
Workshop Participants

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Appendix D

GLOBAL SCIENCE FORUM
MATHEMATICS IN INDUSTRY
Heidelberg, Germany, June 4 - 5, 2007
Editorial Workshop

Location: Internationales Wissenschaftsforum Heidelberg (IWH), University of Heidelberg, Hauptstraße 242

June 4

11:00	Discussion of the Report and the Memorandum
13:45	Sessions of subgroups
15:30	Session of subgroups
20:00	Plenary session ▪ Short reports ▪ Discussion of the panel session at ICIAM Sessions of subgroups

June 5

9:00	Plenary session
9:30	Sessions of subgroups
11:30	Session of subgroups
12:30	Report of subgroups
13:45	Plenary session
16:00	Preliminary end

Participants:

Bonilla Prof. Luis, Spain
Capasso, Prof. Vincenzo, Italy
Gyllenberg, Prof. Mats, Finland
Jäger, Prof. Willi, Germany
Krebs, Dr. Hans-Joachim, Germany
Michalowski, Dr. Stefan, OECD
Niezgodka, Prof. Marek, Poland
Ockendon, Prof. John, United Kingdom
Schuppert, Dr. Andres, Germany
Stockie, Prof. John, Canada

Via electronic mail:

Bourguignon, Prof. Jean-Pierre, France
Jeltsch, Prof. Rolf, Switzerland
Kaper, Prof. Hans G, United States of America
Schilders, Prof. W.H.A., Netherlands
Svanstedt, Prof. Nils, Sweden

Appendix E

Panel Discussion: Mathematics in Industry

6th International Congress on Industrial and Applied Mathematics

The results of the GSF activity were presented and discussed at the ICIAM 07 in Zurich, Switzerland, in a panel session. This congress was the 6th in the series of global conferences of the International Council for Industrial and Applied Mathematics (ICIAM) covering research developments in applied mathematics, industrial applications of mathematics, and the interaction of mathematics with industry and the sciences.

In addition to the regular program of invited presentations, minisymposia, and public lectures, the program at ICIAM 2007 featured several *Industry Days*, where the discussions focused on particular subjects of importance to a specific sector of industry (aircraft design, electromagnetics, food processing, transportation, telecommunications, pharmaceutical, and risk management in financial and energy markets). The congress was attended by more than 3000 participants. For details, see the ICIAM 2007 website, http://www.iciam07.ch/index.

The panel discussion had a prominent position in the programme. The following text is an excerpt of the official programme:

OECD Panel Discussion: Mathematics in Industry

Date: 17 July 2007, 19.15 - 20.30 Room: AudiMax of ETH (HG F30)

Moderator: Willi Jäger

Aims:
Mathematics is a key technology for industry. (Industry interpreted in the broadest sense, including any activity of economic and/or social value.) The panel will present a report prepared for the OECD Global Science Forum on "Mathematics in Industry". The report was prepared by a working group of 60 experts representing the industrial, academic and government communities of 18 member countries of the OECD and Russia, who met in Heidelberg, Germany, in April 2007. The main objectives of the activity were:

- *to survey the state of the art of mathematics in industry in the participating countries, and to identify and analyze the most important challenges;*
- *to formulate a set of standards for mathematical research, education and funding, and to identify the structural changes necessary to improve the transfer of mathematics to industry;*
- *to promote the application of mathematical technology in industry; and*
- *to coordinate or initiate national programs and plan international cooperation.*

The report, which summarizes the discussion and recommendations of the working group, will be distributed to the governments and funding agencies of all GSF member countries to raise the awareness and enhance the profile of mathematics in the industrial context. The panel will explain the motivation for the report and discuss the main findings.

Panellists:

Luis L. Bonilla	*Universidad Carlos III de Madrid; President of ECMI.*
Jean-Pierre Bourguignon	*Institut des Hautes Études Scientifiques, Director*
Vincenzo Capasso	*Advanced Applied Mathematical and Statistical Sciences (ADAMSS), Director, Università degli Studi di Milano.*
Martin Grötschel	*Matheon, Konrad-Zuse-Zentrum and TU Berlin.*
Willi Jäger	*Interdisciplinary Center for Scientific Computing (IWR), Head, Applied Analysis Research Group, University of Heidelberg,*
Rolf Jeltsch	*Department of Mathematics, ETH Zurich; President GAMM; President-Elect ICIAM, Director of ICIAM 07*
Hans Kaper	*National Science Foundation (NSF); Argonne National Laboratory, United States.*
Stefan Michalowski	*Executive Secretary, Global Science Forum, OECD, Paris.*
John Ockendon	*Oxford Centre for Industrial and Applied Mathematics (OCIAM)*

About 200 participants took part in the event. The members of the panel presented and discussed the results of the GSF activity and the recommendations to improve the transfer of mathematics to industry. Structural changes necessary to improve cooperation in mathematical research and education were a central point of discussion. The response of the audience was very positive and the comments during and, for time reasons, mainly after the panel via email, were very helpful for preparing the final report. The headlines of the ICIAM Newsletter July 19, 2007,*"OECD demands new strategy for education of students" and "Education of students required to be more interdisciplinary"*, summarise one of the main concerns debated.

ICIAM 2007
6th International Congress on
Industrial and Applied Mathematics

Newsletter

July 19, 2007

Participants of ICIAM during the refreshment break

OECD demands new strategy for education of students

On Tuesday night, six experts presented the conclusions of a report for the OECD Global Science Forum on *Mathematics in Industry* that was held in Heidelberg, Germany, in April. The report was prepared by a working group of 60 experts representing the industrial, academic and government communities of the OECD and Russia.

> **Education of students required to be more interdisciplinary**
>
> Work in interdisciplinary expert groups is becoming more and more relevant for upcoming challenges.
>
> Therefore mathematics becomes more and more likely to be known by experts from other disciplines.
>
> However, students of mathematics should be encouraged to get insight to other disciplines and hence be prepared for work in the interdisciplinary environment.

The Chair of the panel, Willi Jaeger (Universität Heidelberg, Germany) named some of the objectives of the working group, for example to survey the state of the art of mathematics in industry, to analyze structural changes necessary to improve transfer of mathematics to industry and to identify the challenges of the future.

Tremendous increase of data

Todays world has a tremendous increase not only of data but also of types of networks (for example in medicine, in information technology, in traffic). At the same time there is an increasing demand on quality as well as a level of interaction between different disciplines, Vinceno Capasso (Milano) said.

Willi Jäger from Heidelberg explained that mathematical applications had become much more efficient, due to the underlying algorithms, while improved hardware plays only a minor role.

To cope with these challenges, Jean-Pierre Bourguignon (Institut des Hautes Etudes Scientifiques, France) pointed out that society needs people who understand the language of mathematics. He said that it was important to have good teachers and to find new ways of education: It was necessary to make students of maths aware that their education can lead to many fields in the economy. Students of other disciplines have to learn that it will be necessary to understand the language of mathematics for a mutual understanding of experts. The repesentatives at the panel agreed that it will become more and more necessary to work in interdisciplinary expert groups.

Jean-Pierre Bourguignon, Vincenco Capasso

The report, which summarizes the discussion and recommendations of the working group, will be distributed to the governments and funding agencies of all OECD member states to raise the awareness and enhance the profile of mathematics in the industrial context.