Discussion document for the twentieth ICMI study : educational interfaces between mathematics and industry

L'Enseignement Mathématique (2) 55 (2009), 197–209

COMMISSION INTERNATIONALE DE L'ENSEIGNEMENT MATHÉMATIQUE

(THE INTERNATIONAL COMMISSION ON MATHEMATICAL INSTRUCTION)

DISCUSSION DOCUMENT FOR THE TWENTIETH ICMI STUDY

EDUCATIONAL INTERFACES BETWEEN MATHEMATICS AND INDUSTRY (JOINT ICMI/ICIAM INTERNATIONAL STUDY)

1. INTRODUCTION

The ICMI/ICIAM-Study on "Educational Interfaces between Mathematics and Industry" (*EIMI-Study*) starts from two assumptions, namely:

1. There are intimate connections between innovation, science, mathematics and the production and distribution of goods and services in society. In short: there are intimate connections between mathematics and industry.

2. In view of these connections, there is a need for a fundamental analysis and reflection on strategies for the education and training of students and maybe the development of new ones.

The EIMI Study, organised jointly by the *International Commission on Mathematical Instruction* (ICMI) and the *International Council for Industrial and Applied Mathematics* (ICIAM), seeks to better understand these connections and to offer ideas and suggestions on how education and training can contribute to enhancing both individual and societal developments.

1.1 Tentative description of the field

Historically, there have been productive interactions between mathematics and industry in generating and solving problems associated with the development of humankind, economically and socially. In a modern, technological world, mathematics is said to be used almost everywhere. However, these uses are not generally visible except to specialists. Even people using mathematics in their workplaces may not recognize its presence.

There have been many studies of the mathematics used in the workplace — ranging from descriptive lists of traditional school-based topics to sociological studies of workplace activities set in context. There have been many collections of applications of problem solving and modelling based on or informed by practical industrial problems, especially at higher levels of mathematics, in fields such as the natural and physical sciences, engineering, and finance.

Internationally, there are frequent articles and debates in the popular media citing employer dissatisfaction with the perceived quality of mathematics education. Graduates from schools, vocational colleges, and universities often appear unable to draw upon and use mathematics in work situations as opposed to classroom or examination contexts. At all educational levels, students typically have been taught the tools of mathematics with little or no mention of authentic real world applications, and with little or no contact with what is done in the workplace (be it the classical engineering situations or other more recent activities like biotechnology, biomedicine, the financial, insurance and risk sector or consulting engineering companies).

Nowadays, highly complex problems need to be solved and, hence, some training to solve such problems — in particular, real life problems — is necessary. Increasingly, powerful computers make it possible to treat such complex problems and this is achieved not only using off-the-shelf software but with innovation, often mathematical innovation requiring insight and analysis.

In order to better understand these phenomena, the Study starts from a broad definition of *Industry* (from the Organisation for Economic Co-operation and Development) "... 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" [OECD 2008, p. 4]. The term 'industry' obviously refers to a diverse range of activities, producing goods and services. Under constraints such as time and money, these activities generally attempt to optimize limited — sometimes scarce — resources, both material and intellectual. The overarching goal is to maximize benefits for certain groups of people while, ideally, minimizing harm to other groups and the natural environment.

"*Mathematics* (or the mathematical sciences, here the two terms are used interchangeably) comprises any activity in the mathematical sciences, including mathematical statistics" [OECD 2008, p. 4]. Workers at all levels utilize mathematical ideas and techniques, consciously or unconsciously, in the process of achieving the desired workplace outcome. In other words, mathematics is just one part of a repertoire of tools and strategies of a practical nature. However, as a major factor in decision-making and communication processes, it is crucial that mathematics be used appropriately, accurately, and with confidence. For this Study, we start from the assumption that professional mathematicians are located in academia, in industry, sometimes in both. The discourse of mathematics in all its various specializations involves certain ways of thinking and acting. Traditionally, mathematicians consider axioms and definitions and make logical deductions. In mathematical modelling, one formulates problems in mathematical terms. However, the mathematical solution needs to take into account the industrial context.

This Study will examine the implications for education at the intersection of two communities of practice — industrialists and mathematicians or industry and mathematics. We wish to emphasize that there should be a balance between the perceived needs of industry for relevant mathematics education and the needs of learners for lifelong and broad education in a globalised environment. In other words, learners should be equipped for flexibility in an ever-changing work and life environment, globally and locally.

1.2 Rationale for the study

Who are the intended beneficiaries of this Study ?

- students enrolled in formal education systems across all sectors, including vocational, secondary, tertiary, and even primary,
- pre-service teachers [teacher students] and practising teachers involved in continuing education or professional development programs,
- teacher educators for the above categories,
- learners undertaking workplace education, from low-skilled workers through to management [and their workplace teachers/trainers],
- industry decision makers,
- mathematicians working in industry,
- policy makers.

What are the aims of the Study ?

- to broaden the public awareness of the integral role that mathematics plays in society with respect to low- and high-technology industries,
- to broaden the awareness of industry with respect to what mathematics can and cannot realistically achieve under current circumstances,
- to broaden the awareness of industry with respect to what school and university graduates can and cannot do realistically in terms of mathematics,
- to broaden the awareness of mathematics teachers and educators with regard to industrial practices and needs with respect to education,
- to enhance the appropriate usage of mathematics in society and industry (e.g., by presenting examples of good practice),
- to attract and retain more students, encouraging them to continue their mathematical studies at all levels of education through meaningful and relevant contextualized examples,
- to improve mathematics curricula at all levels of education.

Why is this Study needed ?

- to create new and innovative educational practices and support existing good practices,
- to ensure that, when used as an employment selection tool, mathematics is used appropriately,
- to develop in learners the mathematical reasoning and logical thinking needed in industry,
- to enhance the dialogue and understanding between the communities of mathematicians, workers and industry decision makers, politicians, and educators.

2. The role of mathematics — visibility and black boxes

We all use mathematics every day; to predict weather, to tell the time, to handle money. Mathematics is more than formulas or equations; its logic, its rationality have for a long time gone beyond just numbers. However, people are often not aware of the importance of the role of mathematics in modern technologies. Many people have a restricted view of what mathematics is and does. We need to make the use of mathematics in modern society more visible.

If young people are not aware of the importance of mathematics and have not personally experienced its applicability, they may not want to study mathematics in school. This may limit their career and educational opportunities later on. Many societies have had some kind of selection process, such as Classics (be it studying Chinese, Greek or Latin). Today, mathematics serves this purpose in many countries. This can be progressive, in that it gives children an opportunity for upward social mobility through studying mathematics. However, it can also be repressive in that it can limit the opportunities of students with problems in mathematics. Some people will manage to compensate for gaps in their mathematical training, but others will not. The consequences, political, cultural and educational, are important.

The role of mathematics is twofold. It can give people highly developed skills in abstraction, analysis of underlying structures, and logical thinking. It can also give them experience with the best tools for formulating and solving problems. We will refer to this as analysis. This is in comparison with applying "black boxes", which refers to the packaging of mathematics with other conceptual and material tools into (hopefully) automatic solutions to problems, with the consequence of hiding the mathematics from the immediate view of the users. This packaging can be anything from a fast food cash register, where the keys show only pictures of the items instead of numbers, to the search algorithm in *Google*™. We believe strongly that most people will need a combination of the skills listed above. Knowing only how to apply black boxes has many shortcomings:

- It limits innovation, critical analysis and adjustments to the techniques.
- It does not allow analysis in case of failure of the black box.
- It makes it harder for people to judge the appropriateness of various techniques and the validity of the output.

The exact balance of emphasis between analysis and black box techniques and the various levels of description of the inner workings of the black boxes will depend on the nature of the application.

Questions

1. How can mathematics, especially industrial mathematics, be made more visible to the public at large?

2. How can mathematics be made more appealing and exciting to students and the professionals in industry?

3. How can mathematics serve a progressive rather than a restrictive role in education and training for the workplace?

4. What is the best way to teach analytical skills to various groups of students?

5. To what extent is it necessary or desirable to describe the inner workings of black boxes?

6. What are the social implications of not explaining the inner workings of black boxes?

3. Examples of use of technology and mathematics

Modern workplaces are characterised by the use of very different types of technology. ‘Technology’ is understood in the broadest sense, including traditional machinery, modern information technology, and workplace organisation. Examples include a turning lathe, paper forms for reporting on production, technical drawing packages such as Computer Aided/Assisted Design/Drafting (CAD), and the assembly line as a means of organising production in contrast to other forms of workplace organisation.

The conceptual basis of most “modern” information technology is obviously some sort of (often discrete) mathematics. Reports like *Mathematics in Industry* [OECD 2008] mention university-level examples of uses in the chemical industry, oil exploration, medical imaging, micro- and nano-electronics, logistics and transportation, finance, information security, and communications and entertainment as areas of industrial use of mathematics. It lists mathematical themes such as complexity, uncertainty, multiple scales, large-scale simulations and data and information (see p. 10). As a consequence, one could think that the growth in the use of technology implies an increasing presence of mathematics in the workplace. Research findings and anecdotal evidence seem to point to the contrary: Mathematics is said to disappear from the workplace. At least, mathematics is less visible in modern workplaces than in traditional ones. Why?

One way to understand this paradox is the following interpretation of the situation: As discussed above, technology is a means of packaging mathematics with other conceptual and material tools into ideally automatic solutions of problems, thus hiding mathematics from the immediate view of the users. One side-effect of these black boxes is to secure a certain distribution of technological power, giving the control of a whole range of situations to those few who understand the inner working and intricacies of the boxes.

Questions

1. How is it possible to describe and analyse the role of mathematics within technology? What are insightful examples of the role of technology in showing and/or hiding mathematics in the workplace?
2. Does the existence of special types of technology hiding mathematics from the view of the user imply a change in the mathematical demands on the user? How?
3. To be more precise and to give one example for a more detailed question: With the idea of exact measurement furthered by modern technology, do old competencies like estimation of results and reading of different scales become obsolete when using modern technology? Or, do they become more important?
4. What are the social and political consequences of the ‘crystallising’ and ‘hiding’ of mathematics in black boxes — this question is pertinent not only to modern technology like computers, but also to software and hybrid technology.

4. Communication and collaboration

In the workplace, mathematics is seldom undertaken as an individual activity. Mathematical work, mostly on modelling and problem solving, is almost always a group activity and frequently the groups involved are made up of individuals with diverse expertise and expectations. Communication between and among such groups is crucial. By communication we include listening, writing, speaking and the use of communication technologies as essential skills. A societal or industrial problem may be concerned with making a process faster, cheaper, more robust or, in a general sense, more efficient. But when is the problem amenable to mathematical analysis and solution ? Communication at this level is often difficult because managers, mathematical and non-mathematical team members may come with different training, different goals, and use different languages. They may have to cope with highly complex situations, often marked by uncertainty, the use of multiple scales, sometimes relying on large-scale simulations. Nonlinearity, data and information are important aspects of modern industry [OECD 2008].

In industries of all sizes, small, medium and large, good communication is extremely important in understanding the nature of a problem and its mathematical components. Communication is clearly essential between team members in "solving" a problem. However, translating a mathematical solution into a workable solution can be challenging as there may be confounding social and political considerations.

It is also necessary to understand that in some industrial settings, intellectual property rights and secrecy may be an issue restricting open communications.

QUESTIONS

1. How to identify which societal and/or industrial problems should be worked on ?
2. How to better communicate within multi-disciplinary working groups ?
3. How to communicate the underlying mathematics to the problem owners and/or general public ?
4. How to achieve greater quantitative literacy among school leavers, workers, and the general population ?

5. TEACHING AND LEARNING OF INDUSTRIAL MATHEMATICS: MAKING INDUSTRIAL MATHEMATICS MORE VISIBLE

In Section 1, we described the somewhat paradoxical situation of mathematics being used more and more extensively in modern society, while it is progressively disappearing from societal perception. Let us consider some examples:

- To many primary school students the long division algorithm is a black box.
- Most students have never thought about how calculators compute transcendental functions such as the exponential.
- Google's Page Rank algorithm is a powerful application of eigenvectors in very high-dimensional linear algebra.
- GPS, the Global Positioning System, involves diverse technologies, and its understanding requires geometry, linear algebra and coding theory among others.
- Cryptography is fundamental to modern society. Despite its high sophistication, it involves mathematical ideas that can be presented in a simplified way to a broad audience.
- Weather forecasting shows the power of combining mathematical modelling and high-speed computers.

- Statistics is a useful tool, but many people do not understand how to interpret statistical results properly.
- Computer animation involves many mathematical issues, such as using quaternions to parameterize rotations.

Logistics and decision making are broader fields, which also imply the use of simple and/or sophisticated mathematical technology. In all fields, most of the mathematical technologies are used without realising that mathematics is used; mathematics is normally not even mentioned in relation to them. Teaching and learning of mathematics has to cope with this fact by either hiding mathematics from the view of the learner or deliberately showing the use of mathematics even if this is not obvious. The (in)visibility of mathematics, especially industrial mathematics, implies a major problem in education and training. Nevertheless, describing the inner workings of these procedures can be a great way to motivate teaching and learning of various topics.

QUESTIONS

1. Who decides what will be explained and to whom?
2. How to decide the level of explanation for various groups?
3. How to organise teaching and learning in order to make industrial mathematics visible — if this is wanted/necessary?
4. How much is it appropriate to explain for educational purposes in order to generate interest and excitement without overwhelming the learner?

6. USING TECHNOLOGY AND LEARNING WITH TECHNOLOGY: MODELLING AND SIMULATION

For a better understanding of the role of technology in the educational interfaces between industry and mathematics, it may be helpful to distinguish between technology created and used to help industry do its job — often called *indutech* — and technology created especially to foster teaching and learning mathematics and its use for instance in industry — called *edutech*. Using either kind of technology, especially new technology, usually requires special efforts to become acquainted with it, to develop routines and practice. To put it in workplace words, a special effort (in terms of time set aside) must be made to teach and learn using a specific technology. This can be an obstacle to switching to a more modern technology as long as the older one still "does the job". On the other hand, change and innovation are necessary in industry (especially in times of globalisation).

There are a number of issues related to using technology in industry (indutech) and teaching and learning with technology (edutech). We name just a few:

- Technology may be a reason to make obsolete certain competencies by means of routines packed into black boxes — e.g., simple arithmetic and more advanced handheld calculators may change the role of traditional arithmetic performed with paper and pencil or in the head.
- Technology taken as an unquestionable "god" may call for a critical evaluation of the results, both in industry and in education.

- Technology can be a means to enhance learning by simulating the workplace situation (virtual workplace simulation). This can be technology especially created for teaching/learning purposes as well as the usual workplace technology used in a typical educational way. Simulation — especially of unusual, even dangerous situations — for educational purposes can reveal the inner workings of black boxes. Modelling and simulation may be seen as a way to create opportunities to better understand an input-output system, to see the consequences of certain input variables, and even, perhaps, to understand the mechanisms inside the system.

QUESTIONS

1. How should one decide on the level of detailed mathematics expected to be taught/learned in a given vocational black box situation?

2. How can mathematics help the transfer of technological procedures and/or solutions between different fields of industry?

3. What criteria should be used to judge the appropriateness of simulation in the teaching and learning of industry related practice?

4. How can one compensate for the "standardising effects" of any technology that is in widespread use?

7. TEACHING AND LEARNING FOR COMMUNICATION AND COLLABORATION

As mentioned in Section 3, communication and collaboration form an integral and important part of the industrial use of mathematics. Because of the importance of communication skills for work in industry, is it desirable to have these skills taught and learned in all parts of education and training. But there are additional justifications for including teaching and learning communication skills within mathematics education. To cite a few:

- Modelling industrial problem settings at each level of education can be used to teach mathematics in the context of its contemporary uses. This modelling relies on effective communications throughout the process.
- Teaching communication skills is a natural part of the mathematics learning process (listening, writing, speaking and using communication technologies).
- Assessing communication skills (listening, writing, speaking and using communication technologies) is a natural part of the mathematics assessment process.
- Collaborative learning should begin in primary education and be continued as part of a life-long learning process. Examples include: planning and making healthy soft drinks in primary school, analysing strategic games or simulating running a small business in secondary education, and working on real industrial problems in tertiary education.

QUESTIONS

1. What communication skills are specific to mathematics?

2. Are there specific skills for use in relation to industrial mathematics?

3. How do we teach mathematics as a "second language"?

4. What is the role of mathematical contests and competitions in developing and assessing communications skills in mathematics?

8. Curriculum and syllabus issues

A partnership between mathematics and industry requires adjustments of the mathematics curriculum in order to prepare students for both the needs of mathematics and the requirements of industry. This can also support the teaching of mathematics in general. Students are often taught as if mathematics were a dead science and a finished product. Giving students an opportunity to experience the excitement of realistic applications may enliven their view of the subject.

Questions

1. What are the advantages and disadvantages of identifying a core curriculum of mathematics for industry within the general mathematical curriculum at various levels and for various professions?
2. What are useful ways to introduce mathematics for industry into vocational education?
3. What are the advantages and disadvantages of creating specific courses on mathematics for industry vs. including the topic in the standard mathematical courses at various levels?
4. What are the advantages and disadvantages of treating mathematics for industry as an interdisciplinary activity or as part of the traditional mathematics syllabus?

9. Teacher training

Teachers must be trained in new mathematical content, pedagogy and assessment and to recognize the presence of mathematics in society and industry. This should take place in schools of education for mathematics teachers of all levels, in-service programs, and industrial training programs.

There may be a special need to act on teacher training in areas like statistics, discrete math (recursion, graph theory, matrices), operations research and mathematical modelling in the context of real applications. These curricular changes must be complemented by changes and innovation in the pedagogy offered to teachers, such as stressing collaborative learning, making decisions on appropriate use of educational technology and fostering communication skills. Assessment modes and practices should include informal assessment techniques, portfolio and group assessment.

These changes may be fostered by industry visits or longer-term placements of students who want to become teachers and by practising teachers. Understanding the educational interface between mathematics and industry can be enhanced by current and future teachers actually going into the workplace to observe and talk to workplace personnel as they experience real industrial problems.

Questions

1. What level of understanding of this new content in relation to EIMI is appropriate for each grade level?
2. What are good practices that support this new direction in teacher training?
3. How to implement these changes in an efficient way?

10. Good practices and lessons to be learned

In all sectors of education there are examples of good practice in relation to this Study. To give an example, we mention engineering programs that seem to foster creativity and innovation by final-year projects in a better way than school and university courses in the mathematical sciences. One important aspect of the Study is to communicate and exchange examples of good practices in order to make concrete the ideas already discussed in this document. We would like to collect outstanding examples of innovative practices that are suitable for use and adaptation by teachers at the various levels of education.

Possible examples may include:

- creating *optimal routes* for garbage collection (appropriate at different levels of sophistication starting with 4 year-olds); graph/network theory;
- analysing the *probability concepts* which underpin different card games; probabilistic decision making;
- *analysing data* related to the environment and patterns of consumption such as energy use, clothing sales (appropriate at different levels of sophistication starting with 10 year-olds); statistical decision making;
- *project management* for an event of relevance to the particular students; total project management skills;
- *game theory* (decision making);
- *continuous optimization* — e.g., finding an optimal path on a downhill ski slope.

We are also looking for good examples of how to integrate industry into the educational process. For example, through:

- study groups which address problems brought into the classroom from industry;
- internships (for students and teachers into industry; for industrialists into education);
- summer/winter schools, where industry representatives work together with students on problems of relevance to industry rather than the school curriculum;
- competitions involving mathematics used to solve industry-related problems under realistic conditions;
- the documentation of existing case studies.

Lessons to be learned from failures are of the same interest as those from successes. The examples should include the intended outcomes, the pedagogical practices involved, and a critical evaluation of the process.

11. Research and documentation

Launching this Study, we start from the assumption that, from a global perspective, there is a need to research existing practices; no coverage of the whole field currently exists. Pertinent topics are diverse — with diverse methodologies being appropriate to the field of educational interfaces between mathematics and industry.

Within this research field, mathematical interfaces can include mathematics "proper", but are usually interdisciplinary in practice. Mathematics is part of the method of coping with industrial situations, but can also be the object of study (especially in studies on societal and industry needs and educational practice and innovation). For example, there is a need for studies on the curricular consequences for vocational, secondary, tertiary and primary education.

Compared to other topics, it seems obvious that national and trans-national documentation is widely missing in the field of mathematics and industry (even with CEDEFOP and other institutional databases). Suggestions and contributions describing existing and future research and documentation of activities in the field of Educational Interfaces between Mathematics and Industry will be most welcome.

Participation in the study

Design of the study

The ICMI/ICIAM joint study on *Educational Interfaces between Mathematics and Industry* is designed to enable researchers and practitioners around the world to share research, theoretical work, projects descriptions, experiences and analyses. It will consist of two components: the *Study Conference* and the *Study Volume*.

1) The *Study Conference* will be held in Lisbon, Portugal, on April 19–23, 2010, the number of participants to be invited being limited to approximately 100. It is hoped that the Conference will attract not only "experts" but also some "newcomers" to the field with interesting and refreshing ideas or promising work in progress, as well as participants from countries usually under-represented in mathematics education research meetings.

Participation in the Study Conference will be by invitation only, based on a submitted contribution. Proposed contributions will be reviewed and selections made according to the quality of the work, the potential to contribute to the advancement of the Study, with explicit links to the themes and approaches outlined in this Discussion Document, and the need to ensure diversity among the perspectives. Accepted papers will appear in the Conference Proceedings that will be published by ICMI and ICIAM as a CD-ROM and on the Internet (open access), and will form the basis of the Study's scientific work. An invitation to the conference does not imply that an oral presentation of the submitted contribution will be made during the Conference, as the International Programme Committee (IPC) may decide to organize it in other ways that facilitate the Study's effectiveness and productivity.

The Study Conference will be a working one, every participant being expected to be active. We therefore hope that the participants will represent a variety of backgrounds, expertise, experience and nationalities that will lead to a suitable coverage of the Study theme, its different topics and the related questions. Such attendance should be drawn broadly from the mathematics and mathematics education communities, as well as from industry. It is the IPC's hope that the Conference will attract applied mathematicians, representatives from industry, mathematics educators, in particular those involved in the preparation of school teachers, practitioners in the teaching of applications of mathematics and researchers in mathematics education — both experienced people and young researchers entering the field.

Unfortunately an invitation to participate in the Conference does not imply financial support from the organisers, and participants should finance their attendance at the Conference. It is hoped that this invitation will help participants to get appropriate support from their own countries. Funds are being sought to provide partial support for participants from non-affluent countries, but the number of such grants will be limited.

2) The *Study Volume*, a post-conference publication, will appear in the New ICMI Study Series (NISS), published by Springer. Acceptance of a paper for the Conference does not ensure automatic inclusion in this book. The Study Volume will be based on

selected contributions as well as on the outcome of the Conference. The exact format of the Study Volume has not yet been decided but it is expected to be an edited coherent book that can hopefully serve as a standard reference in the field for some time.

A report on the Study will be presented during the 7th International Congress on Industrial and Applied Mathematics (ICIAM 2011), to be held on July 18–22, 2011, in Vancouver, Canada, as well as at the 12th International Congress on Mathematical Education (ICME-12), to be held in Seoul, Korea, on July 8–15, 2012.

The aim is to present the Study Volume itself at ICIAM 2011.

Call for contributions

The International Program Committee hereby invites individuals or groups to submit original contributions on specific questions, problems or issues related to the topic of the Study for consideration by the Committee. A submission should represent a significant contribution to knowledge about the Study topic and may address questions from one or more of the Study themes (see Sections 1 to 10 above), or further issues relating to these, but it should clearly identify its primary focus. The IPC welcomes high-quality proposals from researchers and practitioners (both from education and industry) who can make solid practical and scientific contributions to the Study. New researchers in the field and participants from countries under-represented in mathematics education research meetings are especially encouraged to submit contributions. To ensure a rich and varied scope of resources for the Study, participation from countries with different economic levels or with different cultural heritage and practices is encouraged. We hope that applied mathematicians, as well researchers and mathematics educators from the early years to tertiary level, will come up with new insights and guidelines for future work. Contributions from vocational education and industrial mathematics are highly welcome.

Those who would like to participate should prepare a 6–10 page paper (Times 14-point font, single spaced lines) addressing matters raised in this document or other issues related to the topic of the Study. All papers must be written in English, the language of the Conference, and include a 200-word abstract. Papers concerning work that is ongoing or yet to be carried out are also welcome. Research questions should be carefully stated and expected results should be formulated, if possible with reference to earlier and related work.

These documents should be submitted no later than September 15, 2009, to both co-chairs of the Study by e-mail. All such documents will be regarded as input to the planning of the Study Conference and will assist the IPC in issuing invitations no later than November 15, 2009. All submissions must be uploaded electronically to the Study website (http://eimi.mathdir.org/) together with appropriate personal data, in the form of a PDF, RTF or DOC file not exceeding 1.5 MB.

Study timeline

- Submissions for participation in the Study should be uploaded to the website by September 15, 2009.
- Submissions will be reviewed and decisions made about inclusion in the Conference Proceedings. Notifications about these decisions will be sent by November 15, 2009 to all those who sent in submissions. In the case of papers accepted for the Conference, some suggestions for changes may be sent to the authors.
- Final versions of papers accepted for the Conference Proceedings must be received by March 15, 2010.

INTERNATIONAL PROGRAMME COMMITTEE

Alain Damlamian, Faculté de Sciences et de Technologie, Université Paris-Est (France), co-chair

Rudolf Sträßer, Institut für Didaktik der Mathematik, Justus-Liebig-Universität Gießen (Germany), co-chair

José Francisco Rodrigues, Faculdade de Ciências, Universidade de Lisboa (Portugal), local organiser

Marta Anaya, Facultad de Ingeniería, Universidad de Buenos Aires (Argentina)

Helmer Aslaksen, Department of Mathematics, National University of Singapore (Singapore)

Gail FitzSimons, Faculty of Education, Monash University (Australia)

José M. Gambi, Escuela Politécnica Superior, Universidad Carlos III de Madrid (Spain)

Solomon Garfunkel, Comap (USA)

Alejandro Jofré, Departamento de Ingeniería Matemática, Universidad de Chile (Chile)

Henk Van der Kooij, Freudenthal Institute, Universiteit Utrecht (Netherlands)

Li Ta-tsien, Department of Mathematics, Fudan University (China)

Brigitte Lutz-Westphal, Institut für Didaktik der Naturwissenschaften, der Mathematik und des Sachunterrichts, Universität Vechta (Germany)

Taketomo Mitsui, Department of Mathematical Sciences, Doshisha University (Japan)

Nilima Nigam, Department of Mathematics, Simon Fraser University (Canada)

Fadil Santosa, Institute for Mathematics and its Applications, University of Minnesota (USA)

Bernard R. Hodgson, Département de mathématiques et de statistique, Université Laval (Canada), *ex officio, Secretary-General of ICMI*

Rolf Jeltsch, Seminar for Applied Mathematics, ETH Zürich (Switzerland), *ex officio, President of ICIAM*

INQUIRIES

Inquiries on all aspects of the Study and suggestions concerning the content of the Study Conference should be sent to both co-chairs:

◊ Alain DAMLAMIAN, *damla@univ-paris12.fr*, and

◊ Rudolf STRÄSSER, *Rudolf.Straesser@math.uni-giessen.de.*

The official website for the joint ICMI/ICIAM Study is http://eimi.mathdir.org/

REFERENCE

[OECD 2008] Organisation for Economic Co-operation and Development *Global Science Forum* (2008). *Report on mathematics in industry.* Available at: http://www.oecd.org/dataoecd/47/1/41019441.pdf