University and Academic Technical/ Vocational Education

Nilima Nigam and José Francisco Rodrigues

1 Introduction

In this chapter we report on the university-level teaching and learning of topics at the interface of mathematics and industry. We focus on questions from several topics from the EIMI document: the Teaching and Learning of Industrial Mathematics, the Teaching and Learning for communication and collaboration, Curriculum and Syllabus issues, and on the Teacher training. We shall see that there is a diverse range of pedagogical and training practices surrounding industrial mathematics internationally. After reviewing the specific questions that the Working Group 5 (WG5) addressed at the 2010 EIMI conference in Lisbon, and which were partially complemented and discussed at the Macau 2011 Workshop, we present some reported experiences, discussions, and recommendations. We also present brief introductions to some selected papers from the Conference Proceedings.

The WG5 met in two sessions and brought together experts with two different perspectives. One group consisted of experts specializing in mathematics education at the university level and in preparation of engineers and applied mathematicians. The other group consisted of researchers and practitioners with experience in industrial mathematics. The works included four short presentations by William Lee (Ireland), Adérito Araújo (Portugal), Avenilde Romo (Mexico), and Edwige Godlewski (France). In addition, there were two Skype presentations by Lou Rossi and Bogdan Vernescu, both from the USA and who were unable to attend the Lisbon meeting in person. The WG5 included, in addition to the presenters, the two coordinators, Pilar Romero, Juan Tejada (Spain), Jaime Carvalho

N. Nigam (✉)
Department of Mathematics, Simon Fraser University, Burnaby, Canada
e-mail: nigam@math.sfu.ca

J. F. Rodrigues
Universidade de Lisboa, Lisbon, Portugal
e-mail: rodrigue@ptmat.fc.ul.pt

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e Silva (Portugal), Ajit Kumar (India), Rudolf Strässer (Germany), Jinxing Xie (China). The questions in front of the WG5 and the presentations were discussed by all the participants. We found the range of international experiences and perspectives to be particularly illuminating. Participants were able to share their experiences and recommendations with each other. Equally importantly, we learned what university-level initiatives did not work in particular contexts; this enabled participants from other countries to reflect upon whether such initiatives could, with modification, succeed in their universities. The discussions and debates were summarized and presented to the plenary by Sarah Peterson (Canada).

The specific questions the WG5 addressed were: (1) How should one organize university-level teaching and learning in order to make industrial mathematics visible? Is this increased visibility of mathematics wanted/necessary? (2) What is an appropriate level of detail for educational purposes in order which can serve to generate interest and excitement in an industrial mathematics problem, without overwhelming the learner? (3) Are there specific skills for use in relation to industrial mathematics, and 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? (5) What are the advantages and disadvantages of creating specific courses on mathematics for industry versus including the topic in the standard mathematical courses at various levels? (vocational training? role of internship?); (6) What are the appropriate levels of understanding, good practices, and guidelines for implementation of new measures in teacher training related to industrial and applied mathematics?

Question 1 *How should one organize university-level teaching and learning in order to make industrial mathematics visible? Is this increased visibility of mathematics wanted/necessary*?

Several participants gave examples and reported their experiences and a first observation raised by this question is, naturally, to whom industrial mathematics should be visible, not only for the students but also for the society, since mathematics is everywhere and it is necessary to make it more visible. On one hand, this depends on the level, and taking the Master's level as example, mathematics should be visible to students as well as their future employers. On the other hand, teachers-in-training often are not exposed to industrial mathematics, but they could be disseminators to students and to the society, as for instance, the case of the interesting Georgia Tech GIFT program. As a difficulty, it was observed that this requires and will put pressure to provide more real-world examples within "service" courses, what is hard for the math professor because often they do not fully know the industrial context of the mathematics they teach. Among the recommendations, we report the following: (1) collaborate with teachers and experts in other disciplines to expose mathematics in context; (2) open some black boxes at every level (e.g., at undergraduate level, write your own Differential Equations solver to understand the software black box); (3) Share and disseminate good examples, e.g., on the Web; (4) Stimulate, encourage, and reward curiosity.

Question 2 *What is an appropriate level of detail for educational purposes in order which can serve to generate interest and excitement in an industrial mathematics problem, without overwhelming the learner*?

First, it is necessary to notice that problems from industry are often not formulated as mathematical problems, and therefore there is a need to learn a lot about the specific context of the problem and to distill essential information for the specific question from the mass of existing details in the application. Then it is necessary to formulate the problem and study the problem mathematically. This requires a student to draw on existing mathematical training and search the literature for relevant ideas. Often, they may need to learn new mathematical concepts. Since many mathematical problems do not have closed-form solutions, the student may have to select appropriate software tools or develop new tools to solve the problem. Finally they have to 'close the loop' by relating their mathematical results back to the specific application of interest.

Several international experiences were described and discussed. A remarkable range of novel pedagogical approached have been implemented globally to enhance the training of students in the use of mathematics to solve industrial problems. Some initiatives are short-term (week-long courses or workshops); others can be long-term and immersive (e.g. internships). In Europe and USA, week-long modeling courses produce very successful results for industry. These are modeled on the successful mathematical study groups with industry (UK, North America, Ireland, Portugal, Australia, China, etc.). In these settings, the problems from industry are not clearly formulated as mathematical questions. Participants have one week to produce newmodels, new perspectives, and insights. When using such a format to train students, it was noted that these short time frames may require students to get help navigating prior knowledge pertaining to the application. Existing week-long industrial graduate-level problem-solving workshops involve a mixture of distilled prior knowledge, and guided problem formulation.

There are also successful examples of longer-term courses. For example, in a University of Delaware final year undergraduate modeling course, students work on real-world problems and develop habits of mind for effective practice of mathematics in applied and industrial contexts. In another successful example in France, a financial mathematics program was developed and taught by academics with actual banking experience.

In mathematical modeling course with large enrollments, as in some institutions in China, it is not practical to have inclass open-ended modeling activities. Instead, students are shown case studies, then encouraged to work on more realistic problems outside class.

We discussed models of industrial internships (e.g., WPI in USA, MITACS in Canada, UPMC, and UPPA in France), which provide immersive (long term) learning experiences. These are ultimately very valuable, but finding suitable industrial internships for a large number of students requires an intensive commitment of resources.

Given this range of pedagogical approaches in use globally, the question of an appropriate level of detail to present must necessarily depend on the level, length and format of the course. Several recommendations on how much detail to present were proposed: obviously, always taking into account that the level of detail depends on level of course: (1) Base activity or course on existing resources, like books, or other materials which are already carefully structured, as in the US Consortium for Mathematics and its Applications (COMAP) or in the Contemporary Chinese Undergraduate Mathematical Contest in Modeling; (2) Present the general problem statement and provide 3–4 relevant articles or sources; (3) Present case studies in class, assign open-ended problems for team-based assignments outside class; (4) Present only the problem statement; (5) Point students to important concepts/courses in other disciplines. The WG5 consensus recommendation was to encourage independent and actual industrial problem-solving, not just passive learning, as well as to. There were divergent opinions on role of books, but there was a consensus that shared resources for industrial problems would be needed; (6) Point students to important concepts/courses in other disciplines. There were divergent opinions on role of books, but a consensus that shared resources for industrial problems would be needed was easily obtained.

Question 3 *Are there specific skills for use in relation to industrial mathematics*, *and how do we teach mathematics as a second language*?

The discussion around this issue started with general and essential non-technical skills, like teamwork, cooperation, communication in and with multi-disciplinary teams, different and specific communication skills needed for academia and industry, presentation skills for different audiences, management of information resources, effective and efficient time management, ability to assess and manage risks, initiative and creativity.

It was observed that any curricula in industrial mathematics should encourage the acquisition of both transversal and specific competences. The *transversal competences* (instrumental, personal and systematic) should not be distinguished from a general Subject Benchmark statement for engineering skills, attributes and qualities, as referred in (Alberti et al. 2010). These are reproduced here by their own intrinsic interest:

- Knowledge and Understanding
  - Specialist (Discipline) knowledge.
  - Understanding of external constraints.
  - Business and Management techniques.
  - Understanding of professional and ethical responsibilities.
  - Understanding of the impact of engineering solutions on society.
  - Awareness of relevant contemporary issues.
- Intellectual Abilities
  - The ability to solve engineering problems, design systems, etc., through creative and innovative thinking.
  - The ability to apply mathematical, scientific, and technological tools.
  - The ability to analyze and interpret data and, when necessary, design experiments to gain new data.

  - The ability to maintain a sound theoretical approach in enabling the introduction of new technology.
  - The ability to apply professional judgment, balancing issues of costs, benefits, safety, quality, etc.
  - The ability to assess and manage risks.
- Practical Skills
  - Use a wide range of tools, techniques, and equipment (including software) appropriate to their specific discipline.
  - Use laboratory and workshop equipment to generate valuable data.
  - Develop, promote, and apply safe systems of work.
- General Transferable Skills
  - Communicate effectively, using both written and oral methods.
  - Use Information Technology effectively.
  - Manage resources and time.
  - Work in a multidisciplinary team.
  - Undertake lifelong learning for continuing professional development.
- Qualities
  - Creative, particularly in the design process.
  - Analytical in the formulation and solutions of problems.
  - Innovative, in the solution of engineering problems.
  - Self-motivated.
  - Independent of mind, with intellectual integrity, particularly in respect of ethical issues.
  - Enthusiastic, in the application of their knowledge, understanding and skills in pursuit of the practice of engineering.

The specific competences depend on each "industry". It can be readily seen that mathematics also has a transversal nature. Transversal mathematical competences should be incentivized in specific courses and can be used to obtain specific competences in many different situations. The *Mathematical and technical skills* were summarized as follows:

- Modeling and analytical skills, knowledge of numerical methods;
- Simulations, experience with mathematical models in industry;
- Ability to handle huge amounts of data by integrating mathematical, numerical, and statistical methods—Ability to identify and select key information;
- Software skills—Students need sophisticated understanding of mathematical software—Programming skills—gain better understanding of "black box" tools, build own tools when needed;
- Ability to apply mathematical, scientific, and technical tools;
- Analytical skills—formulation of problems.

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

Challenging in Mathematics is a classical issue that goes beyond the traditional school and has a well-established tradition in elementary mathematics, in particular in the Olympiads, that encompasses millions of students, teachers, mathematicians, and hundreds of associations all over the world. The topic was even the subject of the 16th ICMI Study (Barbeau and Taylor 2009). The less known first Mathematical Contest in Modeling, was initiated in the USA in 1985 by COMAP, and was followed in 1999 by another series on Interdisciplinary Contest in Modeling. The benefit to the students and the utility for mathematics education at tertiary level was soon recognized in China, where a huge and successful series exists and was reported at the WG5 by J. Xie.

Finally, it was observed that contests and modeling weeks may simulate the real-world workplace and provide a good environment for students learn to deal with time pressure, different time constraints in industry, along with the development of skills like teamwork, presentation of results, etc. It was observed that the inclusive spirit of these contests implies no one fails in competitions. Even if some competitors naturally get prizes, everyone learns and wins with the participation. Students learn to tackle problems with no single correct answer, to identify and use which assumptions should be reasonable. Models should be creative and innovative and the solutions should be justified, efficient, and useful.

Question 5 *What are the advantages and disadvantages of creating specific courses on mathematics for industry versus including the topic in the standard mathematical courses at various levels*? (*vocational training*? *role of internship*?)

First it was observed and commented that the reputation of applied/industrial math versus pure math is an issue in current academic culture. Diverse approaches to overcome the situation were reported. For instance, in the USA, the WPI model integrates modeling and applied problems throughout the curriculum from the ground up and the case of the University of Delaware the students take a modeling capstone in their final year. In China, modeling courses were introduced with great success, and participation in national and international competitions stimulated those courses. In Europe, the situation in several countries was discussed. In particular, the European Consortium of Mathematics in Industry (ECMI) is promoting courses at the master's level, specific to industrial mathematics, in several European universities. Several commentators observed that it is a big challenge to find educational opportunities in industry, but that the Study groups with industry (faculty and stu- 206 dents) are a good tool. Also, modeling weeks for students can prepare them for internships that should be incorporated in their training, as is already often the practice in several universities. It was also observed that the European Science Foundation (ESF 2010) has recently published a Report on a Forward Look with, in particular, the recommendation to academia that ''mathematical societies an academic institutions must harmonize the curriculum and educational programs in 212 industrial mathematics at the European level'', with two ''road map implementations'': the creation of a common industrial mathematics curriculum and the setting up of a pool of industrial mathematics engineers, on one hand, and the development of new criteria to assess and recognize careers in industrial mathematics, on the other hand.

Trying to answer question 5, the WG5 discussions recognized the advantages of a distinct course where students will:

- See mathematics applied to substantial long-term problems.
- Improve their employment opportunities.
- Learn mathematics within a specific context.
- Focus on additional skills (communication, teamwork, interdisciplinary collaboration, etc.).

On the other hand, if there was a consensus that resources should be shared at national/regional level, some disadvantages and difficulties were pointed out:

- Start up cost is high—making industry connections is really hard.
- Students may not have appropriate mathematical expertise.
- Perception problem in some countries –need to convince students and faculty colleagues.

Question 6 *What are the appropriate levels of understanding, good practices, and guidelines for implementation of new measures in teacher training related to industrial and applied mathematics*?

A first observation dominated this point: the majority of mathematics teachers are trained in pure math only, even if some exposure to applied/industrial math already exists in some countries. It was also observed that there are some tools and examples for teachers provided by associations, as COMAP the USA, and by mathematics societies in some countries.

From the contributions to the study and the WG5 discussions the following recommendations were suggested:

- Applied and industrial mathematics societies should provide more materials for teachers.
- Include more applied mathematics examples in existing teacher-training programs.
- Universities should provide lifelong learning/in-service education for teachers (e.g., Georgia Tech GIFT program summer internships, which place teachers in industrial “real world” projects).
- Enable secondary school teachers to highlight mathematical models arising in other subjects (e.g., physics, biology).

2 Complementary Selected Articles

These conclusions and recommendations are based on WG5 discussions at the EIMI conference and on several contributions included in the original proceedings (Araújo et al. 2010). These proceedings contain different articles and reports on developing curriculum options that prepare the students for a career at the interface of mathematics and industry, for strategies to create opportunities for research participation at the undergraduate and graduate level, including industrial internships, modeling camps, and summer schools, as well as on setting up opportunities for secondary school teachers to participate in academic-industrial interactions.

Due to the large number of contributions, it was not possible to include all those that are related to the four Sections of the Discussing Document, namely the Sect. 5, on Teaching and Learning of Industrial Mathematics, the Sect. 7, on Teaching and Learning for communication and collaboration, the Sect. 8, on Curriculum and Syllabus issues, and the Sect. 9, on Teacher training. Nevertheless the following nine articles, edited from the 2010 Proceedings or added after the Macau Workshop in 2011, are part of this WG5 report.

1. *Mathematics for Engineering and Engineering for Mathematics*, by M. Albertí, S. Amat, S. Busquier, P. Romero and J. Tejada, is a report on behalf of the Spanish Committee for Education of the CEMat, which plays the role of ICMI in Spain, the country that hosted the International Congress of Mathematicians in 2006, congregates three types of complementary contributions to the Study. First, a report on mathematics and "engineering" in secondary education, based on research developed in a city in Catalonia that confronts the mathematics is used and how it is used at work, as well as the several characteristics of the industrial field that are absent in secondary education and in mathematics education as well: competitiveness, production, and valorization method of results. Second, an analysis of the mathematical competences in the engineering curricula at university level versus industrial demands, describing the case of the agro-industry of the region of Murcia, with which the Polytechnic University of Cartagena has projects. Third, contains description of some Spanish master programs under the label of "Mathematical Engineering". This part analyzes the examples of two Universities in Madrid (Complutense and Carlos III), and the University of Santiago de Compostela in the European framework.
2. *Laboratory of Computational Mathematics*: *an interface between academia and industry*, by S. Barbeiro, A. Araújo and J. A. Ferreira, is short report that illustrates how a university laboratory, associated to a mathematical research center in Portugal, can act as an interface between academia an industry, with concrete industrial oriented and sponsored research projects, providing support to an educational program and to the integration of students in the job market, as well as integrating the national efforts of mathematics relationship with industry, in particular, hosting an European Study Group with Industry.
3. *Improving the industrial/mathematics interface*, by J. P. F. Charpin and S. B. G. O'Brien. In the context of experience with a network of applied mathematical modelers across Ireland, centered at the University of Limerick, the authors discuss how necessary is the refocusing of our mathematical resources in mathematical modeling, which is central to the practical applications of industrial and applied mathematics, for the regeneration of economic success. Questioning why are mathematicians who participate in industrial mathematics

in the minority and what can be done to improve the situation, the Irish answer states that the solution must lie in the training: mathematics curriculums at all levels need to be redesigned to reflect the ever-growing interest in mathematical modeling and provide the students with the basic skills necessary to become real modelers. As an important tool, the article describes the study groups with industry, which started in Europe in 1968 and is now a well-established institution and a leading workshop model for improving the industrial/mathematics interface all over the world.

4. *Two masters on* '*Mathematics for Industry*' *at the Universities of Paris and of Pau*, by Godlewski et al. (2010). Within the dual French system of higher education, the evolution of the university diploma in applied mathematics at the master's level is described in two different contexts, one in Paris, one in the small provincial town of Pau. These programs have evolved according to the European implementation of the Bologna process; they have taken into account the new range of applications, for instance in Finance, and profited from the spectacular development of computer science. Emphasis on contacts with industry is given, in particular, concerning the computational mathematics and in the professional programs, where the internships are immersed in industry, most often in a private company or in some public research institution. However this contribution does not cover the French recent experience on the educational interfaces between mathematics and finance. In fact, since the beginning of the nineties, Mathematics, and more particularly the theory of probability, have taken an increasing role in the banking and insurance industries, which interactions and their consequences at the level of training in France in these domains as well as at the level of research were also discussed in the WG5 on the basis of the Proceedings contribution (Godlewski and Pagés 2010).
5. *Mathematics in Industry and Teachers*' *Training*, by M. Heilio from Finland, sustains that for education and mathematics teachers' training a change should be visible in curriculum development, up-to-date contents, novel teaching methods and that the development of mathematics modeling education is a crucial part of this endeavor and university pedagogy of applied mathematics. Referring to case examples of industrial math projects illuminating the educational challenge, Heilio suggests and analyzes some implications for teachers training programs and practices at school level, sustaining that a modern view of mathematics should be reflected in curricula and educational practices.
6. *Interfaces between Mathematics and Industry and the Use of Technology in Mathematics Education in India*, by A. Kumar, describes the current situation on interaction between Mathematics and Industry, which is still almost nonexistent in contrast with the rapid economic growth of India, and suggests some of the steps that must be taken in order to improve that interface. A second part deals with the use of computer aided technology in mathematics education at various levels in India and mentions a future project proposed that, in the view of the author, can significantly revolutionize mathematics teaching using computer-aided tools.

7. *Modeling: Developing Habits of Mathematical Minds*, by J. A. Pelesko, J. Cai Louis, and F. Rossi. To develop undergraduate mathematics majors, specific habits of mind associated with the effective practice of mathematics in applied and industrial settings is the central aim of the experience described in report from the Department of Mathematical Sciences of the University of Delaware, USA. Their reform has led to the creation of a new mathematical modeling capstone course possessing many novel features. Over the past years, this course has developed the confidence and ability in their students to see the intimate connections between mathematics and real world processes. This chapter, the authors identify seven key habits of mind associated with effective mathematicians and present best practices for reinforcing these habits in our students.
8. *The evolution of graduate applied math courses in the Institute of Mathematics, University of the Philippines*, by C. P. C. Pilar-Arceo and J. M. L. Escaner IV. This short article describes the recent development of the applied mathematics education in a developing country in Asia by looking into the history and development of graduate mathematics programs in the University of the Philippines Institute of Mathematics. Particular focus is be given to the role industry has played in this evolution and relates lessons learned from past programs, various efforts to promote certain applied math areas and to sustain others which are already strong, valuable collaborations, recent achievements, and future directions. As a late contribution presented at the Macau EIMI workshop, it is a good example of global trends within the educational interfaces between mathematics and of currents interactions between industry in developing countries and academic experiences.
9. *The Vertical Integration of Industrial Mathematics the WPI Experience*, by B. Vernescu from USA, describes several initiatives, including a project oriented education curriculum, introduced almost 40 years ago, at the Worcester Polytechnic Institute (WPI), has facilitated a major change in the mathematics education. Since the mid-1990s the WPI faculty have developed a successful model that introduces real-world, industrial, projects in the mathematics training, at all levels from middle and high school to professional masters, the Ph.D. program and faculty research. The faculty and students affiliated with the Center for Industrial Mathematics and Statistics have developed project collaborations with over 35 companies, businesses and government labs. These projects serve to motivate students to study mathematics and prepare them for interdisciplinary work in their careers. The development of several vertically integrated educational programs are referred and has had funding from NSF, SIAM, the GE Foundation, the Alfred P. Sloan Foundation and Intel.

Two other contributions were also selected and discussed, but since they are also considered in other Working Groups these two contributions appear in the general section of selected chapters in this book:

A Meta-analysis of Mathematics Teachers of the GIFT Program Using Success Case Methodology, R. Millman, M. Alemdar and B. Harris, from USA, reports on the interesting North American experience of the Georgia intern-fellowships for teachers (GIFT) project initiated in 1991. This successful initiative aims to providing first hand connections between classroom activities and real-world applications for teachers in grades six through twelve (students between 12 and 17-years old) with "real life" experiences in the applications of the school disciplines of mathematics, science, and technology.

An Introduction to CUMCM: *China/Contemporary Undergraduate Mathematical Contest in Modeling*, by Jinxing Xie. In the past thirty years, among the most remarkable changes in the educational interfaces between industry and mathematics, the introduction of mathematical modeling courses and a high successful and competitive mathematical contest in modeling are the most important. China university mathematical education in the past thirty years has significantly changed, and will continue to change, in particular the contents and forms of mathematical education. This chapter summarizes the history and current status, including the organizing, training and judging systems, of the mathematical contest in modeling in China universities. The aim of the contest is to expose students to the real-world challenges inherent to mathematical modeling and applications, and provide educational (creativity, challenge, etc.) experience unique to problem bare learning. The contest has been influenced by and has also significantly influenced the teaching of mathematical modeling and applications in China. According to Chinese practice, the contest provides a good educational interface between mathematics and industry.

References

Alberti, M., Amat, S., Busquier, S., Romero, P., & Tejada, J. (2010). Mathematics for engineering and engineering for mathematics: *Proceedings of the EIMI 2010 Conference*, Lisbon, Centro Internacional de Matemática, pp. 11–40.

Barbeau, E. J., & Taylor, P. J. (Eds.). (2009). *Challenging Mathematics in and Beyond the Classroom—The 16th ICMI Study*, Berlin: Springer.

ESF (2010). Mathematics and industry, An European science foundation forward look. http://www.esf.org/flooks.

Friedman, A., & Lavery, J. (1993). *How to start an industrial mathematics program in the university*. Society for Industrial and Applied Mathematics (Philadelphia).

Godlewski, E., & Pagès, G. (2010). Educational interfaces between Mathematics and Finance: the French context: *Proceedings of the EIMI 2010 Conference*, Lisbon, Centro Internacional de Matemática, pp. 227–233.

Godlewski, E., & Madaune-Tort, M., Dossou-Gbete, S. (2010). Two examples of a program 'Mathematics for Industry' at the master's level in a French University: Université Pierre et Marie Curie-Paris 6 and Université de Pau et des Pays de l'Adour: *Proceedings of the EIMI 2010 Conference*, Lisbon, Centro Internacional de Matemática, pp. 211–226.