Second International Symposium on Engineering Systems
MIT, Cambridge, Massachusetts, June 15-17, 2009

On Some Innovative Aspects of the EDAM MIT-Portugal Program

Arlindo Silva, Elsa Henriques, Mihail Fontul, Luis Faria
Mechanical Engineering Department
Instituto Superior Técnico
1049-001 Lisboa, Portugal

ABSTRACT

The authors report and discuss aspects of research and education in the EDAM focus area of the MIT-Portugal Program: innovative PhD program, emphasis on team work involving students with different profiles, integration of interdisciplinary knowledge, specially designed courses to emphasize the Engineering Systems way of thinking and industrial oriented research projects with an Engineering Systems perspective.

Keywords: Engineering Systems, MIT Portugal Program, Graduate Education

1. Introduction

The MIT Portugal Program, denoted in the following by MPP, was launched on October 2006 as a result of the Portuguese Government's strategy to promote national scientific and technological capacity through integrated higher education and research within the domain of Engineering Systems.

To date the Program has already accomplished several initiatives. Relevant to this paper, an innovative group of academic programs leading to post-graduate degrees was designed and launched, involving the cooperation among multiple Portuguese universities in association and with the support of MIT and a framework for educationally coupled and industrially oriented research was established involving collaboration between Portuguese and MIT researchers and Industrial Affiliates in the context of Engineering Systems.

One of the Program's focus areas is Engineering Design and Advanced Manufacturing (EDAM) aiming at advancing competitive product design and knowledge based manufacturing at both educational and research levels. Two degree programs that integrate engineering and management practices are offered in this focus area: a PhD program in Leaders for Technical Industries (LTI) and an Industrial Master's program in Technology Management Enterprise (TME).

In this paper the authors report and discuss some innovative aspects of research and education in the EDAM focus area of the MPP, in particular those that emphasize an Engineering Systems perspective. In the end, conclusions are presented.

2. EDAM and engineering educational programs in Portugal

As happened elsewhere [1], academic engineering in Portugal has relied in industry and government agencies to deal with Engineering Systems issues. However these issues have become much more complex over time – modern developed societies live supported in a complex, interconnected set of overlapping systems – and it is also now recognized that traditional engineering, involving the design of technical products or systems that satisfy well-defined specifications, should also benefit from an Engineering Systems way of thinking.

A main barrier to the development of the Engineering Systems approach in Portugal is associated with the existing engineering educational programs, which are focused on teaching disciplinary knowledge and methods for solving well-defined problems. The traditional educational programs have not addressed conveniently the required competences to deal with multi- and inter-disciplinary knowledge approaches. Sometimes economical issues are considered side by side with technological ones, however, social, organizational, cultural and ethical issues are normally neglected.

The EDAM focus area within MPP opens an alternative to the current situation: a perspective for the Bologna 3rd cycle studies (doctoral degree or advanced studies) aiming to train engineers to develop and manage innovation as a process of integrating multidisciplinary knowledge. According to the MIT-Portugal/EDAM official website: "*The goals for the Engineering Design and Advanced Manufacturing (EDAM) focus area are to develop a new paradigm for engineering education that closely links high quality research to curricular programs, and, to promote an entrepreneurial approach to knowledge-based manufacturing and competitive product design*", the aim is to shape a new type of engineers aspiring to play a leading role as decision makers, responsible for strategic formulations in the field of complex Engineering Systems, with a comprehensive perspective approach regarding an increasingly sensitive society to environmental, social and economic issues.

3. LTI in contrast with traditional engineering PhD programs

Portuguese universities have followed a conservative approach when conducting graduate education coupled with research objectives. A professor or researcher willing to supervise postgraduate students identifies a research topic in his knowledge area, delineates the problem he intends to solve, formulates the research questions and frequently defines the work methodology to be followed. Then he tries to engage the human resources (PhD student). This is essentially a top-down approach from the supervisor to the student, since the latter receives a complete input in terms of problem identification, main research questions and research methodology, and is supposed to follow a well defined and bounded research path.

The EDAM area in the MPP used a different approach to the PhD process. The research proposals come from three main sources: professor/student already involved in a specific research (similar to the top-down approach), Industrial Affiliates suggestions and finally MPP research guidelines (transverse proposals for all MPP Focus Areas addressing industrial based research in national strategic innovation areas). These proposals are presented at the beginning of the first PhD academic year, focusing essentially the main objectives and motivation drivers, and the student is invited to consider the alternatives and decide on his PhD direction. When the proposals are promoted by a group of professors/researchers (from different Universities), the student is expected to engage his research supervisor and research advisors. This is a complex process, and clear rules and an effective involvement and commitment of the EDAM focus area committee in the coordination of the process is a requirement to overcome potential conflicts.

Comparing these two approaches (the classical top-down and the new EDAM) there are two main differences, which translate into advantages and disadvantages for a fresh PhD student. The first main difference results from the approach followed in the PhD proposals process. The student feels much more comfortable when driven by well defined guidelines resulting from a top-down perspective of the PhD work than when he has to identify a research problem, often with ill-defined boundaries, formulate his own research questions and define a work plan to go through. The point here is that after a disciplinary-based undergraduate education most students have difficulty in conceiving a research proposal, especially when it involves multi- and inter-disciplinary research frameworks and when engineering design and advanced manufacturing technical issues mixed with social sciences are supposed to encompass a life cycle outlook for a societal benefit. On the other hand, the student is allowed to spend the first academic year understanding the problem with no confining barriers. This gives him an extra motivation as he can freely decide the research path for the next couple of years. The role of the faculty promoting the research area is critical in this process, as they are supposed to encourage the student as regards creative, critical and scientific thinking and simultaneously provide some guidelines to guarantee that a valid contribution for the global objectives of the research area is undertaken.

The second class of differences results from the mandatory industrial involvement in the EDAM PhD program. In fact, the classical top-down approach that has been taken as a model in Portuguese universities does not encourage a PhD research with an industrial base. Industrial problems may be welcomed, but they are normally considered only at the end of the thesis development, for validation purposes. And at that level the industrial problem must be frequently simplified to allow its accommodation into the research results, meaning that it becomes an uncharacterized industrial driven problem disregarding many important facets. Opposite to this, any EDAM PhD proposal must be built on R&D suggestions of Industrial Affiliates, which are expected to demonstrate a strong commitment with the research work. A PhD student may face conflicting requirements between the academic expectations and those of the industrial affiliate. One should note that the Portuguese industrial economic sectors addressed by the EDAM focus area are mainly composed of small and medium sized companies, without formal R&D departments, and international corporations without R&D competences in Portugal. This kind of companies frequently have a short term vision of innovation and research, within which a set of academic objectives of knowledge generation and leading edge contributions for the state-of-the-art are difficult to frame. However, the proposals defined and in-definition over the first two years of the Program have already demonstrated that academic quality standards, industrial orientation and industrial commitment can be achieved with a close interaction between the faculty, the industry and the students.

4. Successful student team work

Teamwork in multi-disciplinary environments is the trend in industrial environments. There are important issues arising with this way of working, one of them being communication. Fruchter and Townsend studied these patterns and trends in communication issues in multi-disciplinary and geographically dispersed teams and found that, among other conclusions, people try to accommodate their usual tools and methods to allow for some common ground of understanding within the team [2]. Coaching of product development teams is being studied from both an academic and an industrial perspective by Reich et al.. They conclude that this is an important topic for both fields and put forward some profiles for coaching teams. This information is helpful to both students and faculty in the MPP [3]. Ramachandran et al. present a case study that shows the importance of multi-disciplinary and communication in design teams [4]. Richter et al identify the gap of inter-disciplinary learning and tie it to what Moti calls the Engineering Systems approach [5, 6].

The Program emphasizes team work within project-based learning. This project-based learning is thought to be the most effective way of teaching and learning engineering design and Engineering Systems. This also involves bringing together, in project teams, LTI students with solid and fresh scientific knowledge and TME students with strong industrial experience. This mixing of fresh scientific knowledge and industrial experience facilitates looking at engineering problems with open solutions from different perspectives. Regardless of their experience, students can have a background on Mechanical, Electrical, Industrial or Materials Engineering, on Management or Computer Science. In fact, all these backgrounds are present in the Program.

The difference in age and experience was a difficult topic to address during the first year of the Program: LTI and TME students had a hard time trying to work together and resolve their problems. These differences were mostly evidenced when technical issues are involved. LTI students, less experienced, have a more creative and open-minded approach in addressing unfamiliar subjects, while the TME students, more experienced, are more likely to push their professional experience, addressing any new problem in a more confined approach. In the end different backgrounds and experiences and lack of acquaintance with one another made the acceptance of each others' ideas very difficult leading to under-performance in team work.

For the second year, the Program Committee decided to organize a team building activity before classes start, in September 2008. This event made all the difference in the way LTI and TME students worked together from then on. Although there are still (and will always be) differences between them, they know each other better, before working together in teams.

Although originally designed to accommodate rivalry between the three Portuguese universities, the adopted course format – intensive and immersive two week classes rotating among the universities - promotes team spirit and contributes to the work efficiency during the six week breaks in which the main part of the course projects is developed, even if the team is geographically dispersed during the non lecturing periods. This kind of distance working is something that students perceive as the toughest part of their assignments. Being away from each other involves a disciplined approach and, most of all, the establishment of a net of responsibility-trust links among the team members. This is also, paradoxically, one of the highlights that students present by the end of their first semester of the program: learning that they can (have to) work effectively away from their colleagues and co-workers, as long as they have a well defined working structure and tasks and responsibilities are clearly defined. Also, the team building activity is directly tied to this responsibility-trust links that needs to exist when work is being done on concurrent tasks in dispersed locations.

5. Integrating interdisciplinary knowledge

Inter-disciplinary is being pursued at both undergraduate (Bronet et al. [7]) and graduate (Silva et al. [8]) levels. The search for interdisciplinary knowledge at a PhD level has long been identified as mandatory for today's technological and innovation leaders. This is one of the goals of INCOSE and the multiple graduate level programs under the ESD at MIT. Akay calls in his work for a "renaissance engineer", bridging the gaps between the extremely specialized engineers that were at the root of rapid technological development [9].

A considerable effort was made to integrate interdisciplinary knowledge and competences acquired in different courses, based on the joint and simultaneous development of projects for the solution of complex engineering problems. On the first semester of both LTI and TME the students have to take two fundamental courses: Product Design and Development (PDD) and Technology Evaluation and Selection (TES). The former is based on similar courses being taught at MIT and at the three Portuguese universities. The latter is based on similar courses at MIT, but with no counterpart within the Portuguese universities PhD programs. This course is based on three major topics: engineering economics, materials and process selection methods, and process-based cost modeling, with some marginal coverage on multi attribute utility analysis and environmental impact issues.

One example of integration of knowledge from different courses is the joint PDD-TES project. Taking advantage of the courses being taught simultaneously to all the LTI and TME students, this project builds on knowledge coming from both courses to design and develop a product that has to be competitive in the market. Because these two courses are taught at the same time, this offers the opportunity to complement both courses in terms of breadth of learning, without losing the necessary depth of a PhD level course. By using a common project, the student will experience the usual breadth of a product development course, from product planning to production ramp-up, and the depth of the technology evaluation course, with its process-based cost models. During the semester, the students are expected to turn in several homework assignments meant to keep them on track with their project work. Each of the homework assignments has feedback from faculty – some from PDD and some from TES faculty. Even though the in-class time is very short, compared to an average semester, students are always accompanied by faculty feedback on their work. In the end, a final presentation and report, with a mandatory working prototype for each project, are the expected outcomes.

The products coming from these projects are meant to be simple, so that the focus of learning is on the PDD and TES processes and tools, and not on overcomplicated technicalities from excessively complex products. With a simple product, the students can go through all the PD process phases, learning by doing. The mix of students from LTI and TME also increases the learning experience and value of this project.

On their second semester, students have another course – Engineering and Manufacturing Systems (E&MS) – that picks up again the joint PDD-TES project. Each team must look at another team's project, studying and discussing it from a more oriented Engineering Systems perspective. The objective is to highlight development gaps and further enhance a global and systemic view on product development.

6. Development of an overview course for TME

As explained above, two degree programs that integrate engineering and management practices are offered in EDAM: a PhD program (LTI) and an Industrial Master's program (TME). Since the duration of these programs is very different and some courses with Engineering Systems content are not offered for the TME, it was suggested by Frank Field (ESD/MIT) to create a specially designed course to motivate the overall TME educational objectives.

The adopted format – intensive two week classes, with the first week occurring at the very beginning and the second week at the end of TME class schedule – permits the course both to (i) serve as a "gateway" introduction to the other key classes in the curriculum and to (ii) motivate the students to treat the balance of the TME curriculum as training in addressing complex systems and to develop a workable synthesis of this training through their research efforts.

In the first week, the strengths and limitations of traditional engineering approaches to problems are addressed; the gaps in conventional engineering and management paradigms are explored and the benefits of crossing specializations to develop better solutions to problems in large scale and complex technological systems are demonstrated.

An empirical study was conducted in companies with a large number of graduates with different backgrounds in engineering, economy and management to provide concrete illustrations of their different approaches to problem solving and of the limitations of specialization in a single paradigm. These examples are presented as small case studies to motivate the students to learn about fields that complement their current skills.

At the end of the course, students demonstrate the capability of combining engineering and management skills through an in-depth project that requires Engineering Systems thinking and provides a natural integration of other key classes in the TME curriculum.

7. Research projects with an industrial perspective

Industrially oriented research projects proposed and sponsored by the Program Industrial Affiliates are understood as a natural extension of the educational program. In fact, as was mentioned in Section 3, all the students are supposed to be involved in these projects and their research work must accomplish two concurrent objectives: a robust PhD thesis for the scientific state of the art and relevant outcomes in an industrial context. Moreover, the projects proposed by the affiliates must have an Engineering Systems profile, meaning that they are expected to deal with multi- and inter-disciplinary knowledge, include edge technology developments, and critical issues at societal, economical and environmental levels.

As examples of on-going industrially oriented research projects with an Engineering Systems perspective one can mention:

7.1. Lean principles applied in a design environment

One of the research areas proposed by the faculty was the adaptation and application of lean principles for creating an improved framework of the design process in large and complex product development environments. After presenting and discussing this global objective with Industrial Affiliates it was decided to focus it within the context of lean design.

For the Industrial Affiliates the situation was as follows: first steps are being given in the standardization of the product development process to improve its efficiency and efficacy, by increasing its smoothness and consistency. However, they believed in creative environments (focusing on exploring ideas, generating possibilities, looking for many right answers rather than just one) as the ability to create something new and as a starting point for innovation. And creative environments are normally set at a distance from standardization of procedures and of engineering solutions.

Therefore, there is some tension (real or perceived) between the standardization of the product development process required to promote its efficient and efficacy and the enhancement of the creative potential of the design team ("if we standardize we loose the capability to develop creative and innovative new solutions").

The research is aimed at a deeper understanding of the interaction between lean design processes and creativity, focusing the difficulties and main barriers of implementing standardization processes on a complex and creative design environment. The intended outcome will be a proposed framework, to guide the development of standardization and capture the design team motivation towards standardization objectives, based on value stream mapping and design structure matrix.

7.2. Materials selection in a holistic perspective

Material selection is another example of a research area suggested by the Industrial Affiliates. Their main concern was on how to deal with the proliferation of new materials and its impact on existing products and manufacturing technologies. However, the initial suggestion was considered quite limited focusing essentially on materials substitution technical issues. Several discussions involving academia and people from industry lead to a more general and integrated approach, spanning technical and economic analyses at several stages of the product design cycle, including concept generation, embodied design and evaluation, and considering strategic development of manufacturing systems, market and environmental aspects.

Based on these discussions, a structured and enhanced method for material selection throughout the product development process was conceived to conduct the designer on a step by step basis, from what seems to be suitable materials to the "best" material for the application in predefined complex scenarios derived from targets on product performance, economical achievements and environmental impacts over the entire life-cycle. This method is presently being tested using complex industrial cases.

Several new research topics have emerged from these developments, like a systems dynamics based framework to understand the impacts of materials selection all over product life cycle. These methodologies, in addition to their scientific relevance, will contribute to informed decisions in the industrial field.

8. Conclusions

Several fundamental aspects of the MPP have been achieved to date and are described in [10]. Among them, two degree programs – LTI and TME – are offered in association with the EDAM focus area of the MPP and are part of a national strategy to lift Portuguese academic and scientific institutions to an international level within the domain of Engineering Systems.

In this paper some innovative aspects associated with the development and launching of these degree programs are described. They include a PhD program that contrasts in some key aspects with the classical Portuguese PhD process, project-based learning processes that emphasize team work with elements with different backgrounds, intensive course formats different from the typical Industrial Master's programs currently offered, methodologies to integrate inter-disciplinary knowledge and competences acquired in different courses, a specially designed course in Engineering Systems with a unique format that provides a natural integration of key classes in the TME curriculum and industrial oriented research projects that are a natural extension of the education program.

Finally, although not the subject of this paper, the MPP is an exceptional opportunity to introduce changes in the Portuguese engineering undergraduate curricula. This process has already started at IST, one of the MPP's Portuguese universities to which the authors of this paper are associated.

Acknowledgements

We acknowledge the MIT Portugal Program for creating the conditions that made this paper possible and the Portuguese Science Foundation for the financial support of the Program.

References

1. Moses, J., Foundational Issues in Engineering Systems: a framing paper, MIT/ESD, 2004.
2. Fruchter, R. and A. Townsend, *Multi-Cultural Dimensions and Multi-Modal Communication in Distributed, Cross-Disciplinary Teamwork.* International Journal of Engineering Education, 2003. **19**(1): p. 53-61.
3. Reich, Y., et al., *Coaching product development teams: a conceptual foundation for empirical studies.* Research in Engineering Design, 2009. **19**(4): p. 205-222.
4. Ramachandran, R.P., et al., *Integration of Multidisciplinary Design and Technical Communication: An Inexorable Link.* International Journal of Engineering Education, 2002. **18**(1): p. 32-38.

5. Moti, F., *Knowledge, abilities, cognitive characteristics and behavioral competences of engineers with high capacity for engineering systems thinking (CEST).* Systems Engineering, 2006. **9**(2): p. 91-103.
6. Richter, D.M. and M.C. Paretti, *Identifying barriers to and outcomes of interdisciplinarity in the engineering classroom.* European Journal of Engineering Education, 2009. **34**(1): p. 29 - 45.
7. Bronet, F., et al., *Product Design and Innovation: Evolution of an Interdisciplinary Design Curriculum.* International Journal of Engineering Education, 2003. **19**(1): p. 183-191.
8. Silva, A., E. Henriques, and A. Carvalho, *Creativity enhancement in a product development course through entrepreneurship learning and intellectual property awareness.* European Journal of Engineering Education, 2009. **34**(1): p. 63 - 75.
9. Akay, A., *A renaissance in engineering PhD education.* European Journal of Engineering Education, 2008. **33**(4): p. 403 - 413.
10. www.mitportugal.org