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MECHATRONICS MANAGEMENT A BSC PROGRAM

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Abstract: Emerging economies in the midst of fundamental restructuring of higher education can benefit from radical approaches to engineering education programme design. The authors present the case of the development of a BSc curriculum in Mechatronics Management for one of the new international universities in Kosovo in order to demonstrate that it is possible to develop higher-education programmes in advanced engineering, which have local economic context in an emerging economy. The authors illustrate how it is possible to use theories of engineering and technology professional competence to develop a coherent higher education programme which has the potential to deliver on aggressive economic and educational objectives.

1. INTRODUCTION

Mechatronics consists of the integration of mechanical engineering with electronics, computer systems, and advanced controls to design, construct, and operate products and processes. Mechatronics is one of the newest branches of engineering with far-reaching applications. Generally, a mechatronic system can be seen as a mechanism, which is driven by actuators that are controlled via microelectronics and software using feedback from one or more sensors. Mechatronics is therefore the title given to the sub-discipline of engineering which studies the integration of mechanical and electronic technologies to create 'intelligent' machines, systems and controllers. Mechatronics is an interdisciplinary field integrating Mechanical Engineering, Electronics, and Computer Science.

2. ENGINEERING MANAGEMENT EDUCATION & MECHATRONICS MANAGEMENT

Up to now, conventional engineering education throughout Europe, has been dominated by technical subjects, and had little to offer in terms of interdisciplinary academic training. Topics relating to economics, business management and jurisprudence have typically been addressed through short ‘on-the-job’ courses as part of ongoing professional development within the workplace, rather than as compulsory subjects within the context of third or fourth level engineering programmes. On the other hand, graduates from business schools, for example, have rarely had the chance to extend their knowledge in technical fields again developing these skills through ongoing (and typically short) professional development programmes organised through work or some professional body.

Fischer (2004) compared 138 Engineering Management Programs worldwide. His results are summarized in Figure 1 which illustrates the key subjects covered across these programmes. Firstly, it is apparent from the figure that the subject domain typically includes a combination of technical and non-technical subjects focussing upon general engineering. Secondly, Figure 1 implies a high demand for graduates with non-technical skills from these programmes, as compared with the skill profiles of graduates. This further suggests an imbalance in the profiles of the programmes as against the demands of the organisations that employ the graduates of the programmes.

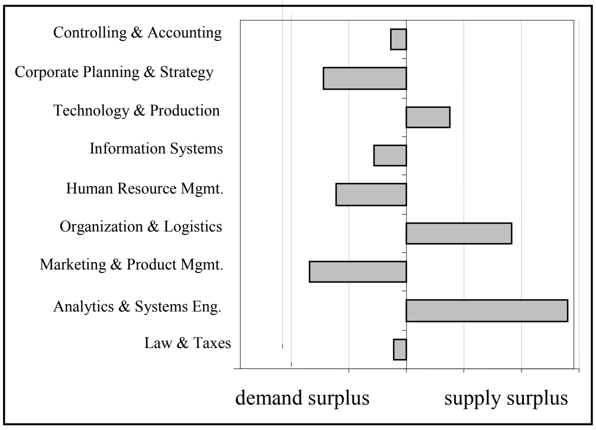

Fig. 1. Summary of Results of Review of Engineering Management Programmes (adapted from Fischer (2004)).

Fischer (2004) indicated how to design a Mechatronics Management programme targeted at developing future engineering managers for developing countries. This provided a baseline for the programme described in this paper. It was clear that mechatronic managers must possess the core skills of mechanical engineers and electrical engineers as well as management and business. Their knowledge enables them to solve a wide range of mechanical, electrical and software problems, allowing them to participate in and lead multidisciplinary design teams. Mechatronics managers have particular opportunities in developing countries.

3. DEVELOPING A MECHATRONICS MANAGEMENT PROGRAMME

A number of well-educated economically-disadvantaged so-called “second” and “third” world societies have recognised the potential of developing a knowledge economy from a low level of development. It is readily apparent that similar opportunities exist for Kosovo, once socio-economic and political stability has been achieved (Ceccarelli et.al., 2006).

All this suggests the need for a new type of degree programme, requiring a non-traditional approach to curriculum development in engineering and advanced technology. This in turn implied the need for a new approach to the development of higher education inter-disciplinary programmes, especially in advanced engineering.

Typically, innovation in science, technology and engineering education has been somewhat constrained by well-established faculty structures present within European universities. The programme team recognised that the educational context provided by a completely new university in Kosovo (i.e. the University for Business and Technology - UBT) was ideal for reworking engineering education curricula along more interdisciplinary lines as is proposed by the recent developments in education research in this domain. The establishment of UBT as a completely new higher education institution in 2004 provided an excellent opportunity to work across traditional faculty boundaries, whilst anchoring the course within a particular disciplinary domain. UBT thus represented a ‘green-fields’ site with a small but extremely motivated staff and student body. This in turn provided an ideal opportunity to design and deliver a truly interdisciplinary programme in “Mechatronics Management”, a programme which was grounded in the reality of mechatronics in its industrial setting in a developing economy.

4. CURRICULUM DESIGN

Surprisingly, mechatronics has received comparatively little attention from engineering education researchers. For some years, and as illustrated for example in both Fischer (2004) and Devereux (2004), concerns have arisen about how to best prepare under-graduate engineers to work with advanced technologies in organisational contexts. Academicians and engineering managers have identified several key areas for engineering and technology educators to focus on.

Failure of advanced technology projects has often been attributed to non-technical rather than technical problems. Research has postulated that the poor treatment of non-technical issues within advanced engineering programmes has contributed to systems failure, as those charged with designing, developing and implementing the technologies have not been provided with the necessary set of skills and knowledge needed to manage these non-technical issues. As a result, high profile professional bodies have called for a greater balance between technical and non-technical competences of technologists (for example review websites of Just IT Training & Recruitment; JP Morgan and Goldman Sachs International).

Professional competence theory therefore provided a particular useful conceptual underpinning for the development of this programme. Carlile (2001) set out a model of education which is based upon developing key competences according to a generic model of professional competence. Devereux (2004) took Carlile (2001) and other models (including ACM, IEEE and IFAC models) and adapted and validated a model of professional competence for technology graduates in industry. Using a case study approach, she then mapped this model of professional competence onto third level advanced technology programmes in order to assess the extent to which these programmes addressed professional competences needed by technologists in the workplace. In setting out her framework of information technology professional competence Devereux (2004) draws upon several literatures, including education, IT, Management and Engineering. Devereux described the following key dimensions of educational competence for information technology and systems professionals:

1. Technical Competence: the individual has sufficient subject knowledge and can plan and organise so as to achieve maximum results
2. Administrative Competence: the individual has a range of business knowledge, can follow rules, procedures and guidelines set out by the organisation and can perform to the expected standards set out by the organisation
3. Ethical Competence: The individual has moral standards which guide them in their decision making activities in the work environment
4. Productive Competence: The individual is efficient and capable of producing desirable results. Productive competence particularly focuses upon the capability of the professional to continuously develop their knowledge and skills.
5. Personal competence: The individual can manage time, possesses necessary ‘people skills’, time management, communications and conflict management skills to operate effectively in the working environment:

In terms of *technical competences*, the fundamental courses provide essential knowledge of mechatronics through related disciplines. The main focus was on natural science so that a solid foundation was laid for basic technical knowledge related to mechatronics technologies. This included subjects such as Mathematics, Physics, Chemistry, Engineering mechanics, Materials, Computer Science, Information Technology, Electrical Engineering and Electronics.

As regards *administrative competences,* Business fundamentals included Economics, Accounting and Statistics. It also demonstrates an attempt to address the broader definition of ‘technical competence’ set out in Devereux’s (2004) competency framework.

The main goal of the above design was to develop a curricula which would enable a mechatronics graduate to be conversant with business issues, and appreciate these in the context of the implementation of mechatronics technologies.

Furthermore, *ethics* was included as a mandatory subject for the curriculum (Stapleton and Hersh, 2004). Very few engineering and technology undergraduate programmes in the western hemisphere incorporate ethics as a major subject so that this is a relatively new approach. There are clearly particular difficulties associated with establishing new institutional arrangements and often, quite radical, structural changes when developing a market driven socio-political-economic system from a marginalised, essentially centralised society. Therefore, it was particularly important that graduates would be well grounded in business and engineering ethics.

Productive competence refers to the ability to 'learn-to-learn' and the thinking skills central to knowledge-based roles. The preparatory course also incorporates 'Creativity and Learning Skills' to provide a basis for developing productive competences as set out in the programme's competency framework. This competence was closely related to the 'knowledge' competence associated with *technical competence* in this framework. Much of the research on higher education learning has focussed upon delivery methods, especially criticising didactic forms of delivery. Consequently, this programme emphasised practice-based learning and problem-centred learning.

As with numerous other programmes the issue of team working was primarily addressed through the delivery modes designed into the programme. The course was also preceded by courses in business communications in order to instil in students, at the earliest possible date, the importance of communication skills.

The final year project/thesis was designed to prove the candidates' ability to describe a special but usually very narrow field of interest with a deeper study. Through the integration of enterprise studies and related management knowledge in the program, it was envisaged that participating students would have the necessary skills and know-how to use the project as a basis for business start-ups. In this way the programme could directly support the economic growth aspirations of region.

Finally, it was important that the curriculum would be 'fun'. For many prospective students, science and advanced technology courses are perceived to be extremely difficult and not inspiring. Consequently, it was felt that the programme needed to incorporate 'edutainment' i.e. to involve problems set in both an entertaining and educative context.

The next section of this paper sets out the equipment associated with the programme, and designed in order to develop some of the various competences and educational objectives indicated above.

5. THE MECHATRONICS LABORATORY

In the laboratory (Kopacek, 2006) , classroom topics were reinforced through a sequence of progressively more complex investigations into the components configuration and control of mechatronic systems. The experiments could be partitioned in the following units:

- Fundamentals of electr(on)ics, pneumatics and hydraulics,
- Programmable logic control (PLC) experiments,
- PC applications,
- Production automation
- Conventional as well as "advanced" robotics.

Therefore experimental setup included breadboards with electr(on)ic and pneumatic components, light stacks, conveyor belts, servo motors, electric and pneumatic actuators, assorted sensors as well as a flexible manufacturing system and a stationary and mobile, intelligent robots.

One of the main goals in selecting the lab equipment was to create a synergy between education and research (reflecting the problem-centred orientation of the programme's delivery mode). Most of the lab equipment was selected so that it met industrial standards. Consequently, ot could be used for industrial-oriented education and research in form of project works and BSc. and in the future MSc Theses. It was also designed so that it could be reconfigurable and extensible. This would support the longer term objective of taking the programme to post-graduate level, at least to level 9.

4.1. Basic Equipment

In the first stage – basic - the following equipments are currently available in the new mechatronics lab:

A modular, flexible production system with 3 different stations, consisting of stations for: handling, processing, distributing, testing, sorting of different parts and a pallet transfer system.

The system was designed for training and research in the following fields: handling technology, assembly and disassembly, logistics, PLC programming, electro – pneumatic, sensor technologies, analogue measurements, position control, conveyors, I/O communication, AC motors, frequency converter.

The system consisted of industrial components and the stations are able to operate independently - e.g. the PLC can be used separately as well as in other systems. Furthermore the stations could be arranged in different configurations.

Laboratory system for fundamentals of pneumatics and electro-pneumatics.

The system consisted of: single and double acting cylinders, 3/2 way and 5/2 way solenoid valves, relais two and three fold, electrical limit switches, proximity switches (electronic and optical), pressure sensors, flow control valves and an user interface.

The system was designed to be used for training and research for the following subjects: structure, function and application of single- and double-acting cylinders, application and function of 3/2 and 5/2-way solenoid valves, logic operations: AND/OR/NOT/NOR/NAND/ XOR etc., combinatorial and sequential logic circuits (synthesis and analysis), function and application of limit switches, sensors and sensor technology, pressure measurements, pneumatic and electrical interfaces, and trouble shooting in simple electro-pneumatic circuits.

All components were designed to be easily attachable. This would provide the flexibility needed in order to meet emerging demands such as designing an aluminium profile plate to ensure an ergonomic working position. This plate was installed in a mounting frame on a mobile trolley for ease of use, mobility and flexibility.

All the components were able to operate independently and in the system and could be combined in different configurations.

Laboratory system for fundamentals of PLC (SPS).

The system consisted in the first stage of :

- *A CPU Module* with16 digital inputs and 16 digital outputs with status LEDs
- *Analog Expansion module* with 4 inputs and 4 outputs
- *Temperature module* with 4 inputs for thermocouple or resistance temperature detector (RTD)
- *A Fieldbus* as well as an *Ethernet Interface* allows the communication with CPU modules and the connection to industrial devices.
- The module was equipped with a watchdog circuit. Its monitoring time could be set via software.
- *Simulation Software* offers a simulated plant environment for function tests of user blocks and programs independent of the availability of actual target hardware. The system had to support at least the standard programming languages statement list (STL), ladder logic (LAD) and functional block diagram (FBD) and fully integrated in the programming environment of the CPU module mentioned above.
- *Data acquisition interface board* with 16 ADC channels either 16 x single-ended or 8 x differential with a resolution of 12/14 bit and a sampling frequency of 500 kHz. The Software included drivers for Windows 95, 98, NT, 2000 and XP with documentation. Drivers and function libraries supported Visual C++, Visual Basic, Borland C/C++ und Delphi as well as Agilent VEE and LabVIEW.

Education robot.

This robot was one of the largest education robots available and was capable of a load capacity of 1.2 kg, depending on its configuration. It had five degrees of freedom controlled by the drive unit, which included the CPU and other electronics. The robot was programmable by means of PC-commands and was connected by either a Centronics interface or via an RS 232 interface. With the TEACH BOX the robot could be moved point to point and both programs and points were stored in an EPROM.

Robot soccer system.

This system was designed to deliver the edutainment context set out in the last section. Experiences in the Technical University of Vienna had indicated that young mechatronics engineers could use this context to deal with complex mechatronics problems in an entertaining, team-based context. For example, experiences in Vienna University of Technology had demonstrated how the construction and manufacturing of the robots body required excellent knowledge of (precision) mechanics. Students needed to develop an understanding of electrical as well as control engineering principles in order to work with the drives and the power source. The control and communication board of the robot presented Austrian students with problems in the area of applied electronics. The microprocessor served as an internal controller and was responsible for the wireless communication with the host computer. For these tasks and for the software of the host computer fundamental knowledge of computer science was necessary. In contemporary robot-soccer systems, the software of the host computer was usually responsible for image processing, game strategies, control of the own players, communication with these. Another important task associated with the development of a robot soccer system was the design and configuration of the user interface. Experiences at IHRT/VUT showed that robot soccer had attracted many students to attend courses, to finish Higher Diploma (level 8 and level 9) and Doctoral theses (level 10). Consequently, it was agreed that this would provide an excellent context for mechatronics problem-based learning.

In Kosovo, the designed system consisted of 11 mobile Mini-robots “Roby Speed” including acceleration sensors, 2 CCD colour cameras, 2 frame-grabber cards, 2 transmission stations, 12 transmission modules (869 MHz), 1 battery charging station and basic software. This system could be also used for research in the following subjects: Communication between agents, Intelligent local sensor implementation, Intelligent behavior of robots.

Three finger hand.

The three finger hand was low cost and easy to operate. It consisted of three fingers with 3 joints and one actuator. Each finger was equipped with one force sensor and the closing time is 2 sec. Objects between 10 and 100mm could be grasped. The maximum payload was 0.5kg and the weight of the hand was 1.5kg.

Additional Components.

Various sensors for pressure, force, position, proximity, light, acceleration. Software: LABVIEW, Matlab/Simulink, SPSS were also incorporated into the educational technology package of this programme.

4.2. Organisation for effective, active learning

In order to outline management aspects associated with the educational technology, the following section sets out some of the relevant organisational and management elements for the lab courses.

- Training material i.e. Teaching material – Transparencies, CD or DVD - for students as well as lecturer and teaching assistants, is available in both English and Albanian, for all systems as well as the components.
- Attendance to the tutorials and labs was stipulated as mandatory
- Students could have 24 hour access to the laboratory and to the wireless connected PC room.
- A tight coupling between lecture and laboratory activity was set out
- Arrangements were to be made for all preparatory tasks to be completed prior to the tutorial in order to avoid time wasted and basic errors which would delay the tutorial session.
- Technical support was set out for the tutorial and lab sessions which would be delivered by people who understand the problems and how they could be solved
- component data sheets as hardcopy in the lab and on course website to be provided.
- a clear handout with the tasks to be solved to be provided
- a large flip chart or whiteboard available to discuss "on site" questions of common interest is to be available for all sessions
- Timeframe: The laboratory equipment was to be completed in the next two years during the development of an MSc degree i.e. the fully functional, research-capable laboratory is to be fully operational in Kosovo with all management and support systems in place by end-2009.

6. SUMMARY

The proposed program provides broad-based bachelor-level education in the basic principles of electrical, mechanical and computer engineering as well as business, information systems and human skills. It fills a major gap in current mechatronics programmes by focussing, in a balanced way, upon both technical and non-technical aspects of mechatronics management. In particular, the focus upon enterprise, systems engineering and mechatronics, as well as the provision of a broad foundation in science. It was envisaged that graduates would be sought after by a wide variety of prospective recruiters. Furthermore, graduates will have the necessary acumen to start-up their own companies which is a critical issue for the development of the emerging Kosovan economy.

It is clear that this program was one of the first trials worldwide to educate "Mechatronic Managers" and is certainly the first to base such a programme in an emerging, post-communist economy. The essential ingredients set out above are unique for the proposed program of study in a number of ways. Firstly, they are dedicated to the special interests of participants in their real-life work context. Secondly, the foundation program provides a wide range of key competencies from computing and engineering to soft skills and management in a single engineering degree. And reflect the theoretical foundations set out earlier in this paper.

Usually Mechatronics programs are pieced together from a combination of lectures from existing engineering programs. Therefore, they address an incomplete mosaic of professional competences associated with mechatronics management. Based upon a well-defined educational competency framework directed at advanced technology curricula, the designers of this programme had the opportunity (and challenge) of designing an entire mechatronics degree program from the start in a green-fields site in an emerging economy. The program was particularly dedicated to realities of small and medium enterprises in small (developing) countries without ignoring the requirements of large engineering employers. The difficulties involved in balancing all these goals in a single objective, and creating a single coherent programme should not be underestimated. The main goal of this program was to educate engineering managers in the field of mechatronics with specific emphasis upon new companies so that the graduate is capable of starting-up, expanding and managing effectively a small or medium-sized company.

Benefits for the graduates:

They are educated in technical fields (IT, ME, EE, Electronics,….) as well as in management (Acc., Fin., …….)

They can open an own company

They can work as a project manager or as a head of a department in a company (Medical, Agriculture,…)

They can work in a governement in a higher position.

They are educated on a international level and could attend the MSc program in Mechatronics Management.

7. OUTLOOK

This BSc programme will start in the summer term 2008 at UBT in Prishtina. Furthermore, the Universidad "Federico Santa Maria" in Valparaiso, Chile is interested to introduce an adapted version of this programme. At the "Escuela Politechnica National - EPN" in Quito, Ecuador a postgraduate Master course based on this curriculum is also in discussion at the time of writing.

In the framework of a new TEMPUS grant a MSc programme in "Mechatronics Management", according to the Bologna convention (European Commission, 2000), is in development. The successful team will continue under the same headlines.

The laboratory will be completed with additional modules of the electro-pneumatic education unit and one additional station of the FMS. A mobile, 6 wheeled, intelligent robot platform should serve for education and research in control engineering, path planning and control. As indicated earlier, this MSc programme and the completion of the laboratory is planned for delivery in 2009.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

Devereux, N. (2004). *Information Technology Professional Competence: An Empirical Study of Irish Higher Education,* M.Sc. Thesis, WIT, Ireland.

European Commission (2000): *The Bologna Declaration – an Explanation.*http://ec.europa.eu/education/policies/Bologna/Bologna.pdf.

Fischer, G. (2004): *Industry and Participant Requirements for Engineering Management*. PhD Thesis; VUT, Vienna

Kopacek, P., M. Ceccarelli, E. Hajrizi and L. Stapleton (2006). Mechatronics education and International stability the development of university level education programmes in advanced engineering in Kosovo. In: *Proceedings of the Improving Stability in Developing Nations Through Automation ISA '06*, Elsevier IFAC publication, p. 1-8

Kopacek, P. (2006). A Mechatronics management laboratory. In: *Proceedings of the Improving Stability in Developing Nations Through Automation ISA '06*, Elsevier IFAC publication, p. 37-42

Stapleton, L. & Hersh, M. (2004). 'Technology Development and Ethical Decision Making: Identity Factors and Social Construction', *Proceedings of International Multitrack Conference of Advances in Control Systems*, Tech. Univ. of Vienna, Elsevier.