DIDACTICAL ASPECTS OF MECHATRONICS EDUCATION

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Abstract: Increasing pressure is placed on universities and vocational training schools with their links to industry to expose students and apprentices to real working environments in education and training of multi-skilled technicians. This led to a new type of job profile which contains a mix of electrical, mechanical and IT knowledge (mechatronics). The paper contributes to these target demands with the development and evaluation of a new kind of multi perspective learning environment for vocational education and training of technicians and skilled workers in the field of mechatronics.

Keywords: mechatronics, education, training, simulation, learning environments

1. INTRODUCTION

Mechatronics can be regarded as a methodology to achieve an optimal design of electromechanical products. The ideas and techniques developed during an interdisciplinary process provide the conditions to raise synergy and provide a catalytic effect for finding new and simpler solutions to traditionally complex problems. There is a synergy in the integration of mechanical, electrical, and computer systems with information systems for the design and manufacture of products and processes. The synergy can be generated by the right combination of parameters, that is, the final product can be better than just the sum of its

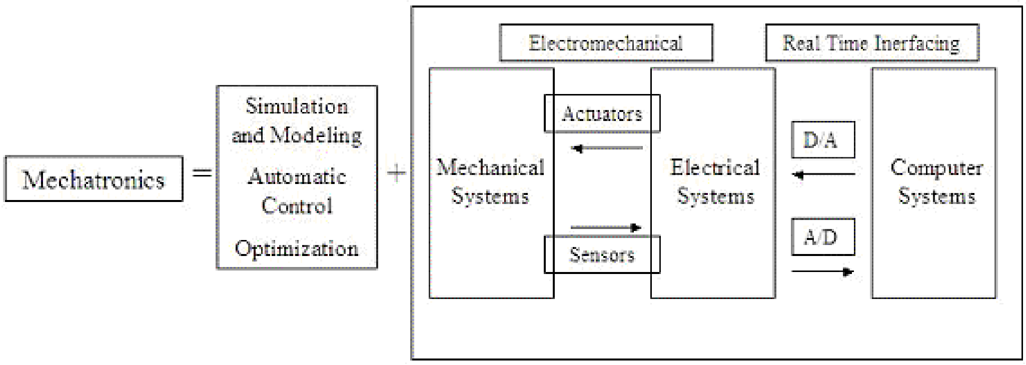

Fig. 1. Key Mechatronic Elements (after Shetty et al, 2002)

parts. Mechatronic products exhibit performance characteristics that were previously difficult to achieve without this synergistic combination. Figure 1 shows the key elements of mechatronics.

Mechatronics is the result of applying information technology to physical systems. The physical system consists of mechanical, electrical, electronical and computer systems as well as actuators, sensors, and real time interfacing. Sensors and actuators are used to transduce energy between high power, usually the mechanical side, and low power, the electrical and computer or electronic side. The block labeled mechanical systems frequently consists of more than just mechanical components and may include fluid, pneumatic, thermal, acoustic, chemical, and other disciplines as well (Shetty et al, 2002). Mechatronic devices are meanwhile of great importance for automotives (aircrafts, automobiles, field robots, CNC-machine-tools, etc.). Interesting is also an integration on the micro- or nano-scale. Microdrives used for minimal invasive surgery are a field of application.

Besides the education and training of engineers for design and manufacturing of mechatronic devices technicians and skilled workers are to be trained for implementation and service. New job profiles are created as a mix of mechanical, electrical and IT knowledge called mechatronics technician. These skilled workers have their tasks mostly in service of products of the above mentioned automotive industry. It is obvious, that the dissemination of mechatronic systems simultaneously requires adequate service techniques. Mechatronic components can easily be integrated into telematic environments and into corresponding concepts for tele-service such as remote diagnosis and maintenance of mechatronic systems. The emergence of remote service techniques has benefits for mechatronic engineering and plant construction industries as well as for their customers: problems can be diagnosed off site and local skilled workers can be supported by a central team of remote experts. At the same time, communication between the manufacturer and the user of mechatronic systems is improved. This helps to reduce service costs while increasing the availability of systems. The increasing dissemination of mechatronic systems in combination with tele-service implies new demands to the skilled workers and technicians.

2. DIDACTICAL CONCEPTS

Vocational training schools together with industry are confronted with the need to develop theoretical integrated with practical learning sequences to fulfil the demands for multi-skilled technicians and skilled workers. Tasks and problem solving in mechatronics requires cognitive and operational knowledge and practical experience about building systems, diagnosis- and maintenance-techniques. However, a significant challenge is that these tasks are essentially characterized by the use of tele-medial systems. Service staff in the professional field need the ability to achieve their aims in (tele) cooperation with others, and they should be able to cooperate in virtual and supranational forms of organization. Until now there exist no elaborated concepts concerning pedagogical, technical and organizational aspects to meet these requirements in education and training. Cultural differences and similarities concerning learning and collaboration styles can be noticed but have not sufficiently been integrated into curricula, courseware and teaching methods.

2.1 Formal Learning in Classrooms

Computers are now used in the classroom as multimedia tools to provide alternative sources of learning material, to provide interactive learning situations and to provide simulation of systems that cannot for reasons of cost, size or safety be used in reality. The use of the Internet is rapidly increasing and is being seen by some people as the greatest source of knowledge available for learning. The use of simulation tools has a number of benefits to education. The learner is not exposed to the hazards of the real world. The learner is able to explore a range of possible solutions easily and quickly. The learner is able to use the tools that will be available in industry. The cost of simulation tools is significantly less than the real world components and allows more participation and interaction than a limited demonstration. An added benefit is that learners today, enjoy using computer based technology and this enthusiasm fosters the learning process. However, it is not clear, how much of real experience can be replaced by learning with simulations.

The German National Institute of Professional Education (BIBB), responsible for occupational training profiles in industry, defines the following skills for workers and technicians in the field of mechatronics (Borch, 2000):

- plan and control work processes, monitor and evaluate the results and apply quality management systems;
- process mechanical parts and assemble sub-assemblies and components into mechatronic systems;
- install electrical sub-assemblies and components;
- measure and test electrical values;
- install and test hardware and software components;
- build and test electrical, pneumatic and hydraulic control systems;
- program mechatronic systems;
- assemble, dismantle, secure and transport machinery, systems and plant;
- set up and test the functioning of mechatronic systems;
- undertake the commissioning of mechatronic systems and operate such systems;
- deliver mechatronic systems to clients and provide training in their operation;

- carry out maintenance operations on mechatronic systems;
- work with technical documents in English-language and also communicate in the English language.

The vocational training schools are teaching in so called learning fields, i.e. approximately 12 to 14 *holistic* problem solving or tasks distributed over three years of training with increasing requirements to the learners. This is a new didactical concept avoiding the former distribution of learning contents into separate classes for mathematics, materials, electrotechnic, mechanic, manufacturing, etc., whereas the learners had been left alone to find out the connections between these contents.

2.2 Informal Learning at workplaces in enterprises

Enterprises have come to realize that employee expertise is a vital and dynamic living treasure. The desire for employee expertise is meaningless unless an organization (enterprise) can develop it in ways that respond to its business needs. Many enterprises rely on off-the-job training (formal learning) without considering its suitability for the learning tasks at hand. On-the-job training (informal learning) has a substantial advantage: it is more close to the problems to be solved and it can be organized in a cooperative way crossing the border between different professions that are involved in a project to fulfill an order of a customer. But on-the-job training is often unplanned and therefore mostly ineffective. With a structure and using well prepared training material usable at the workplace and facilitating advises from outside for cooperative learning makes on-the-job training a powerful tool (Jacobs and Jones, 1995):

- employees work in projects (small groups of different professions) to solve problems,
- employees learn how to learn and think critically,
- employees identify the skills needed to meet the requirements posed by current work,
- employees develop a personal theory of management, leadership or empowerment.

What enterprises need is a culture of expertise, for the good of both the enterprise and the individuals in it. Employees should be encouraged to engage in continuous learning activities – but not to forget that learning and doing go hand in hand. Learning by itself does not lead to enhanced productivity. But expertise can be attained only through learning. Having a learning culture is prerequisite to promote expertise. Analyzing a task to be learned often brings insights into ways of performing a task. Training modules can be used as a way of documenting and storing task information for purposes other than training.
Collecting case studies of solved problems in manufacturing and service could help to solve new tasks. If they are released and are available in electronic format, preferably via internet , it is a powerful instrument for learning at workplaces. Via the internet it is also possible to use training material and remote labs offered by training institutions.

2.3 Bridging formal and informal learning, theory and practice, the abstract and concrete in mechatronics

As the profession of mechatronics is rather new, there is no elaborated didactic for mechatronics education yet. Only some first thoughts and empirical hints can be given. The following main tendencies in mechatronics are considered important:

- thinking in abstract categories of structure-behavior-function searching for alternative concrete instantiations (e.g. various structures for one function, or various functions of one structure)
- thinking in categories of information-control-work process and their realization
- searching for unified systems dynamics views (e.g. Petri-Nets and Bond Graphs) for analogous physical phenomena (electricity, pneumatics, force-momentum mechanics …)
- judging about the adequateness or failure of simulation models versus real systems

A theoretical framework for this didactic requires more insight into how individual learning styles use individual learning media and paths to develop meaning and concepts from basic experiences with natural and technical phenomena. However the development of learning environments should not wait on such a foundation. Instead, we suggest some iteration between Learning Environment development and theoretical derivations based on empirical studies. In several research projects, we found hints for further extensions of learning theory and practice.
In a project "Computer based transitions between concrete and abstract models of production systems" (RUGAMS) funded by the German Research Association (DFG), the possibility and advantage to

Fig. 2. Systems Design by Demonstration

specify an abstract solution for an automation problem by concrete demonstration was shown (Schäfer & Bruns 2001). Users could build a conveyor belt system with concrete modeling bricks and teach the control rules for the flow of workpieces just by doing it with sensorised hands (data gloves), Figure 2. A simulation model and the driving PLC-program (programmable logic controller) could be generated more or less automatically via Petri-Net technology. This yields valuable insight into the relation between the concrete structure and behavior of a system and its abstract IT-representation, contributing to the development of better judgment.
In a European project "Bridging Reality and Virtuality with a graspable user interface" (BREVIE) a system was developed, where students could construct pneumatic circuits in reality with real cylinders and valves, test its functionality and at the same time generate a virtual symbolic simulation and 3D-visualisation representation of the circuit (Brauer et al, 2000). Technologically this was done by video-recognition of all part- and tube-positionings on a laboratory desk. Students then could freely switch between real concrete and abstract virtual modes of operation.

3. EXAMPLES OF LEARNING ENVIRONMENTS

3.1 Electro-Pneumatics

The European project "Distributed Real and Virtual Learning Environment for Mechatronics and Tele-service" (DERIVE) extends the above mentioned concepts to electro-pneumatics and to programmable logic controllers (Bruns et al, 2002). A unified concept of *hyperbonds* (Bruns, 2001) provided means to freely combine real and virtual worlds. This allows the distribution and concrete instantiation or abstraction of interesting parts of a complex system to different locations and on different levels of abstraction conforming to the need of learners, their interests, pre-knowledge and pre-skills.
DERIVE provides a new learning environment that supports vocational schools to deliver courses in mechatronics. The support for the learning process will be reflected in a graduation from local real to local virtual to remote virtual to remote real, taking the student from basic knowledge to the full implementation in industry.
The tele-cooperation functionality in the learning environment will allow enterprises to use the training facilities of vocational schools and/or other providers for updating their employees. With new equipment being more complex and requiring more complex maintenance, the training requirements for workforce and engineers increases. The new environment will allow groups of employees at remote locations to take part at the same training using the same equipment (either simulated or real). This staff will be able to work in a collaborative way to solve problems and explore learning situations. This new kind of interaction will allow the systematic support of skilled workers and engineers by teachers in vocational schools. Also, the DERIVE learning environment is an appropriate tool to realize project orientation in technical training, providing a platform for self-managed and collaborative learning.
One further focus of the project was the analysis and development of innovative mixed reality human

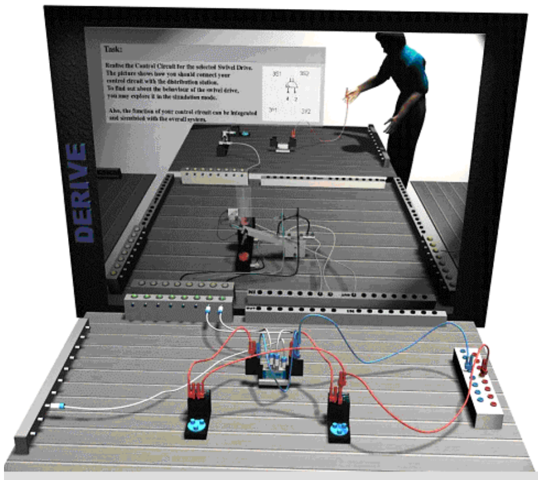

Fig. 3. Real and virtual environment for training in electro-pneumatics

computer interfaces (Figure 3). To develop adequate technological and pedagogical concepts for e-learning in future technical training, user need must be analyzed in depth. The requirements of different user groups (students, teachers, employees) were described and consolidated. Acting in an environment, where real world objects and IT-technologies are applied simultaneously, requires new concepts of supporting cooperating local and distributed learning groups. The scientific challenge is to handle physical as well as virtual presence and awareness without confusing side effects for the users. DERIVE evaluates the user-friendliness of the developed software, analyze the established communication and tele-cooperation behavior and qualify the learning benefit of the system prototype.
DERIVE developed a mechatronic learning environment where on-site and remote components merge into a cooperative learning process. The envisaged system allows to work together with complex real and virtual mechatronic systems, consisting of parts which may be distributed all over the world. The learning environment includes a supportive web-database with multimedia learning sequences providing theoretical background information, exercises and help to handle training tasks. Mechatronic hardware equipment can be connected to the virtual environment with a special sensor-actor coupling. Real electro-pneumatic circuits can be directly imported into the virtual world via image recognition facilities. The DERIVE learning environment smoothly integrates equipment and supports full hardware-in-the-loop functionality,

allowing to build up real mechatronic systems as subsystems of complex virtual systems (Figure 4).

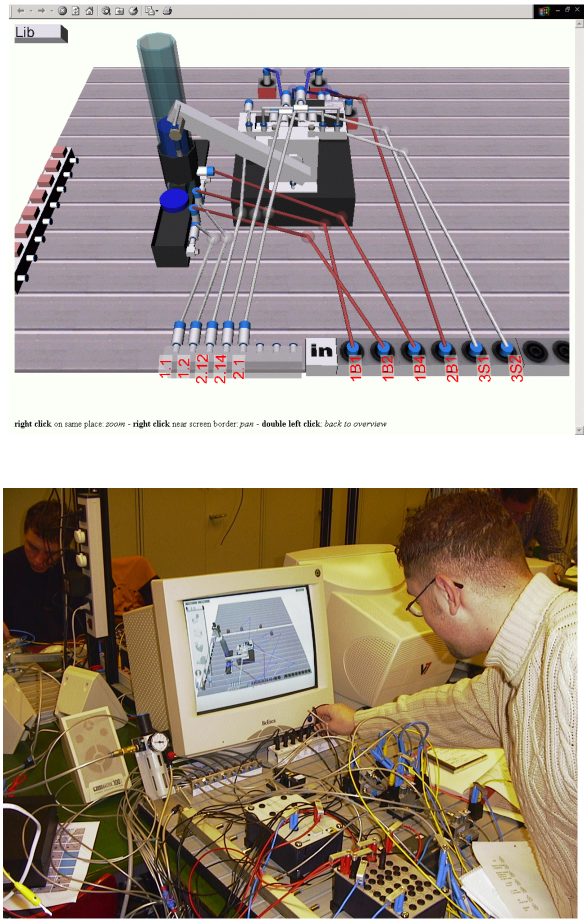

Fig. 4. Student in the lab, problem solving

The environment has been evaluated in 3 European vocational schools and colleges and at one industrial site. The results, based on a prototype which was not yet very stable, was already very encouraging for further offering a broad learning-landscape to navigate between concrete and symbolic representations. In a comparative evaluation of

- traditional teaching with blackboard and teacher learner interaction
- support by simulation only (FluidSim-software of FESTO AG, Germany)
- support by real complex system only (Modular Production System/MPS of FESTO AG, Germany)
- support by real and virtual media (DERIVE)

in 20 hours-courses of mechatronics Grund and Grote (1999, 2001) found some hints that students/aprentices beeing trained with DERIVE showed better performances in construction tasks and fault finding, whereas for the factual knowledge no significant differences could be observed.

3.2 Mechatronics and Tele-service

The aim of a European project "Virtual Laboratory in Mechatronics: Access to Remote and Virtual E-Learning" (MARVEL) (Bruns & Müller, 2002) is to implement and evaluate learning environments for Mechatronics in Vocational Training in schools and enterprises, that allow students and employees access to physical workshops and laboratory facilities from remote places. The project covers concepts that merge real and virtual as well as local and remote worlds in real time (Figure 5).

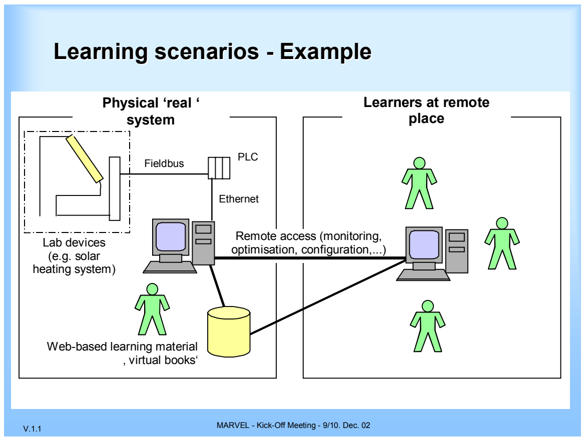

Fig. 5. Real and remote virtual system

This supports tele-actions and remote laboratory experiments in mixed reality work environments. MARVEL produces evaluated working examples of remotely accessible practical environments together with supporting e-learning and student assessment material for the following application fields: robotics, modular production systems and process control. This includes the creation of actual demonstration models (learning scenarios and environments) in partner institutions and enterprises for evaluation purposes. Thus the MARVEL project is intended to stimulate learning concepts, that serve an actual need in the mechatronics industry. Main target groups of the MARVEL project are students in vocational training and employees of enterprises, where learning is integrated in the daily work. Main teaching subjects are system control, maintenance, process monitoring, automation technology of networked mechatronic plant and machinery on the basis of remote techniques (tele-services). The MARVEL concept is intended also to have impacts on life long learning and extended vocational training of full time workers (mobility and flexibility through the combination of local and tele-courses). It also helps vocational training institutions to offer mechatronic courses in cooperation with industry partners, using remote techniques.

3.3 Control of a 3-axis Milling Machine

In classroom and laboratory courses at the Technische Universität Berlin for teachers in mechatronics at vocational training schools the control of a milling machine has to be developed. The small machine is equipped with drives (dc-motors with velocity control using a tachometer feedback, planetary gear and tooth belts) and rotational as well as linear encoders (Figure 6). A program written in PASCAL translates and elaborates on NC-code data to generate digital signals to a D/A-converter that is connected to the drives. The students can change subroutines of the PASCAL-program regarding the accuracy of axis-movements. The encoders provide a Timer/Counter card with data regarding the position of the milling tool. The students have to develop and test different strategies for position control. As a test serves the milling of a circle with different feed rates (TU Berlin, 2002).

Fig. 6. Workplace in the Lab.

4. CONCLUSIONS

Universities and Vocational Training Schools are challenged to provide the industry with engineers and skilled workers for the interdisciplinary field of Mechatronics. As this field of research and application is in a steady development the curricula cannot be fixed for a long period as it is mostly the case in mechanical and electrical engineering education courses. Education and training institutions have to be in close co-operation with industry demands, and to transfer research results into praxis via educating the personnel.

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