Abstract—Mechatronics is an interdisciplinary field which sets challenges for the development of teaching. Aalto University will build its operations on top-quality research and research-based education. In a learning-centered culture students are guided towards a strong commitment to their studies and to taking responsibility for their own development. This is achieved in mechatronics by emphasizing the hands-on, learning by doing approach in teaching. Self-study kits, lab exercises, project work and scientific writing has been used to achieve desired learning outcome. Freedom to contribute to the working methods and increased responsibility of the projects has been found to be inspiring and motivating for the students. In addition to the knowledge acquired students learn the design process of mechatronic project and encounter the challenges that cannot be met in theoretical studies. The experiences and feedback from project based education encourage to continue the development of teaching to even more student-centered approach.

I. INTRODUCTION

Mechatronics is an interdisciplinary field, which requires non-traditional approach to education. While the definitions vary basically mechatronics encompasses the disciplines of mechanical and electrical engineering. Completed with control and systems engineering mechatronics allows design of complex electromechanical products and manufacturing processes. Optimal design of a mechatronic system is a concurrent process. Mechatronics engineer needs multidisciplinary knowledge and must be able to work successfully in projects with multicultural teams. Mechatronics engineer should acquire an understanding in different fields, such as, mechanics, electronics, programming and control theory. The education must build both expertise and working life skills.

There has been a considerable interest on mechatronics curriculum development in universities the world over, see e.g. [1] and [2]. Project-based learning has been widely used and the results have been good. Students have been enthusiastic though the work load might be hard [3]. The use of lab kits for exercises ([3], [4] and [5]) encourages students to experiment with new ideas and even improve the kits. Self-study kits make it possible to take teaching out of the classrooms which also requires less teacher hours than traditional lab exercises. Project work gives the students better understanding of the practice of engineering and they will learn how to think critically and acquire strategies for problem solving [6].

University education should prepare students for scientific approach. The linkage between research and teaching can be described using research-teaching nexus (Fig. 1.). Students are likely to gain most benefit from research when they are involved in it. Research-based curriculum emphasizes research processes and problems and students undertaking inquiry-based learning [7].

STUDENT-FOCUSED
STUDENTS AS PARTICIPANTS

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TEACHER-FOCUSED
STUDENTS AS AUDIENCE

EMPHASIS ON RESEARCH PROCESSES AND PROBLEMS

According to its strategy, Aalto University was established to strengthen the Finnish innovation system by way of integrating expertise in science and technology, business and economics as well as art and design. The university will build its operations on top-quality research and research-based education. In a learning-centered culture students are guided towards a strong commitment to their studies and to taking responsibility for their own development. At Aalto University the mechatronics education is arranged by the School of Engineering in the Department of Engineering Design and Production. Mechatronics is included in the Machine Design major as advanced special studies. There is also a Mechatronics minor, which is recommended for mechatronics students. The courses provided by Machine Design in master program are Mechatronics Machine System Design (4 cr) and Mechatronics project (8 cr). In the minor the essential courses are Mechatronics Sensors and Actuators (4 cr) and Mechatronics Exercises (4 cr). In Mechatronics minor there are elective courses of electronics, control theory and automation that are provided by the School of Electrical Engineering. Mechatronics Sensors and Actuators gives an overview of a mechatronic system and the physical phenomena, basic theory, operating principles, essential features applications for conventional sensors and actuators. Mechatronics Machine System Design makes the students familiar with ways to apply general product development and machine design methodology in interdisciplinary mechatronic machine system design. Both of these courses utilize lab exercises and demonstrations in teaching. Small projects with Lego Mindstorms are also carried out. This paper focuses on the project-based courses in the curriculum.

The education in the project courses is based, besides project-based learning, on learning-by-doing. Students design, manufacture, assemble and test the systems they are working with. After some basic training the students have the responsibility to acquire information when needed. It is clear
that one cannot master everything so it is important to distribute the knowledge. Multidisciplinary operational environment with different projects requires learning from each other as well. At the best mechatronics can achieve something that is more than the sum of its components. Ability to co-operate is therefore essential skill. Therefore the project teams are working in the same room with other projects. There are regular meetings during the semester where projects teams present their advancement and report possible problems.

II. LEARNING ENVIRONMENT

Students have laboratory facilities at their disposal round-the-clock with a keycard. Everything needed for the projects are available in laboratory on two levels with total floor area of approximately 500 m². There are manufacturing equipment (Fig. 2.), machine tools, both CNC and manual, electronic workstations (Fig. 3.) and possibility for circuit board production. Students are allowed to use the production equipment after training and proven capabilities of operating them. There is a basic stock of regularly needed materials and components and more can be acquired according to the needs. The laboratory also offers rooms for CAD-design, meetings, video conferencing and recreation. A lab technician works alongside with the students and helps them when needed.

Fig. 2. Machine tools in the laboratory.

Fig. 3. Electronic workstation in the laboratory.

Training kits (Fig. 4.) and laptops are available for self-study in the laboratory premises. An ATmega128 based microcontroller board is used for exercises to learn programming and interfacing microcontrollers. Three different kits have been designed and constructed starting from simply flashing LEDs according to push button or potentiometer input ending to PWM control of DC motor and navigation using digital compass module. In their projects students are allowed to use a controller of their choice and typically it will be an Arduino based controller board because of the easy approach. It is easy to program, does not require a programming device, there is a large variety of versions, large support community and ready-made libraries not to mention low price.

Fig. 4. Basic microcontroller learning kit.

III. MECHATRONIC EXERCISES

Mechatronic exercises is a 4 credit one semester course offering a first opportunity for undergraduate students to build a device that reacts to the environment and executes its task in a controlled way. For most of the students it is the first time they can see their own design coming into operation.

A. Learning Outcome

After the course, student
- can design and carry out a simple mechatronics system based on microcontroller
- can design simple electronics
- can choose basic components for common uses
- can identify basic concepts related to embedded systems.

B. Exercises

Typically there are 3 members in each team. Project ideas will be suggested for the teams but most teams choose to have their own projects. Good examples of these projects are:

Self-balancing skateboard that uses gyroscope and accelerometer with a PID controller to keep the board and rider balanced (Fig. 5.).

Self-stabilizing quadrotor helicopter that uses gyroscope and accelerometer to assist the user in the flight control (Fig. 6.).
Antilock breaking system for RC car to control each wheel of the car separately which makes e.g. traction control possible.

GPS-based control system for a fishing boat that would follow previous paths and allow manual control via an Android phone.

While above-mentioned projects represent advanced level tasks, students have the possibility to engage in project more suitable for their current knowledge and skills. Examples of these entry level projects are:

Line follower constructed using only passive electronic components.

Solar tracker which is designed to track the position of light with reference to the highest light intensity in the surrounding environment.

Fig. 5. Self-balancing skateboard.

Fig. 6. Quadrotor helicopter.

IV. MECHATRONICS PROJECT

Mechatronics project is a 8 credit one academic year course for graduate students. Hands-on project has always been the core content of the course. Since 2011 the task has been to build working research equipment and use it for research. The project ideas have been derived from ongoing research projects of the department.

A. Learning Outcome

After completion of the course the student

• is able to design and build a new mechatronic product or test equipment according to task description
• is able to work systematically in a multidisciplinary team and to analyze different alternative solutions and to make motivated decisions on basis of this
• can choose the essential methods, practices and components to design and build a mechatronic machine.

B. Projects

Academic year 2011-2012 the projects were:

Patternless sand mold milling machine. A fast numerically controlled sand milling machine was designed and built as a first step towards a new fast and flexible patternless molding system. The first generation prototype machine includes option for multiple cutting heads, which share a common xy-axis but are independently controlled on the z-axis. The tool paths were created from a CAD-model using a CAM-program.[8]

Tracking system for satellite ground station. Aalto-1 is the first Finnish satellite and its design follows the popular CubeSat nanosatellite standard. To handle the communication with such a small satellite orbiting the earth, a ground station with an accurate tracking antenna is needed, to communicate with the satellite while it passes over the station. The system consists of an antenna connected to a computer controlled rotating actuator, attached to a mast (Fig. 7.).[9]

Dynamic loading system for air bearing testing. Air bearings have many benefits over conventional bearings such as low friction and small clearance. The purpose of this

Fig. 7. Tracking system for satellite ground station.
research was to design and build a dynamic loading system for air bearing tests. A low voltage piezo-electric actuator was selected. The effect of dynamic load was observed by measuring air film thickness with eddy-current sensors, loading force with load cell and air consumption with flow meter. Two types of air bearings were investigated: an orifice compensated air bearing and a porous material air bearing.\[10\]

Device for branch volume measurement. The volume and cross-sectional area of tree as a function of its length can be estimated by mathematical models. To create the models representative measurement data is required. This study presented an automated measuring device which is faster and more accurate than the traditional methods. The device consists of a fluid-filled container, metallic frame, electrical lowering system and measurement electronics. While lowering the branch into a fluid container the fluid surface lowers system and measurement electronics. While consisting of a fluid-filled container, metallic frame, electrical water level and the measured weight.\[11\]

The measured branch weight decreases due to the Archimedes principle. The branch volume can be calculated from both water level and the measured weight.\[11\]

Ink-jet printing of pharmaceuticals. Traditional table manufacturing process has multiple powder handling and mixing phases. Modern ink-jet printing technology has been successfully applied to polymer electronics and biomaterial applications. This study examined how well current printer technologies function in printing different types of drug and coating solutions on paper-like substrate. The suitability of ink-jet printing technology was tested by using commercial ink-jet printers which were modified for continuous printing process.\[12\]

In addition to these projects each year a team of mechatronic students, students of automation engineering and students of agriculture (from Helsinki University) participate in an international Field Robot Event. Their task is to build an autonomous robot capable of performing predefined tasks on a field, e.g. maze field.

Instead of writing a final report of the project, the documentation is done in the form of a scientific paper. Last year the papers were presented in an international conference.

V. MECHATRONICS CIRCUS

The courses culminate to the Mechatronics Circus which is an end gala where the project outcomes are presented (Fig. 8.). University administration and representatives from the industry are invited to the happening. High school students from nearby schools, especially science-oriented, are invited as well. This serves as a good means to introduce science and engineering in practice to potential future students.

The projects will have their own stands to demonstrate the projects but there is also artistic content such as circus performances following the theme. The guests have an opportunity to test and experiment with the results of the projects. The Circus is a clear endpoint to a yearlong, occasionally demanding and tiring course.

VI. ASSESSMENT AND FEEDBACK

In the assessment the project outcome is naturally taken into account but failure to achieve the target does not mean failure of the course. The project teams give a peer evaluation of other teams and each team also reflects its own learning process and learning outcomes during the project.

Feedback from the students has been very positive. Hands-on approach and project work are seen as good methods to learn. The possibility to actually manufacture your own product is a good change to traditional courses because it may bring out problems that cannot be seen in theoretical design. Students have learnt the structure and different phases of the design project. Working with real budget adds reality to working. Team work, peer support and freedom to choose working methods and even the project subject are considered inspiring and motivating.

Students seem to have need for practical training alongside with theory. Experience of being able to apply theory to practice encourages students and builds their self-efficacy. Although the writing of the scientific paper increased the work load it was considered educational. It was much more interesting than writing an ordinary document at the end of the project. But there was also lot more work to write conference papers than ordinary reports.

One thing that still needs development is the guidance of students in problem situations. The tutors should be able to recognize the situations where guidance is needed. Students should not waste too much time with challenges that have a recognized solution. This is naturally a question of teaching resources as well.

VII. DISCUSSION

Mechatronics is challenging subject to define and teach. The synergistic nature demands expertise in all related fields but one teacher cannot master everything. The role of the teacher is more like a coach or trainer than traditional lecturer. Teacher will support the students in the adoption of scientific, experimental approach to learning and take care that work load is shared equally in teams. Students, on the other hand, need skills to be systematic and responsible in the approach to learning. They obtain information actively and search and develop new solutions and applications to solve tasks and challenges. Students also have to be able to work in groups.
interactively. Like in research in general, a high tolerance for uncertainty from both teachers and students is needed. Real world problems and possibility to choose own project ideas result in higher motivation. It has been shown that students take the challenge when given freedom, resources and responsibility to manage their projects. However, it is the responsibility of the teacher to take care that the workloads in projects stay on a reasonable level.

Following the reform of the undergraduate program at Aalto University beginning in the fall of 2013 a rethinking of mechatronics education is again in order. It will provide a possibility to widen the scope of mechatronics education, in addition to engineering sciences, to arts and business as well.

REFERENCES


