Mechatronic control engineering and electro-mechanical system design - two mechatronic curricula at Aalborg University based on problem oriented and project based learning.

Pedersen, Henrik C.; Andersen, Torben Ole; Rasmussen, Peter Omand

Published in:
Proceedings of the 10th International Workshop on Research and Education in Mechatronics, REM2009

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

MECHATRONIC CONTROL ENGINEERING AND ELECTRO-MECHANICAL SYSTEM DESIGN - TWO MECHATRONIC CURRICULA AT AALBORG UNIVERSITY BASED ON PROBLEM ORIENTED AND PROJECT BASED LEARNING

Henrik C. Pedersen[1], Torben O. Andersen[1], Peter O. Rasmussen[1]

[1]*Aalborg University, Department of Energy Technology, DK-9210 Aalborg East, Denmark*

Abstract: Unlike most other engineering disciplines, mechatronics as an engineering discipline do not relate to one specific technical field, but is instead a multidisciplinary engineering problem that not only require knowledge about different technical areas, but also insight into how to synergistically combine technologies optimally, to design efficient products and systems. Mechatronic engineering is in this way about mastering a multitude of disciplines, technologies and their *integration and interaction* and should be taught as such.

This paper first considers how mechatronics is typically conceived and practised using a subsystem based approach. The challenges related to teaching and learning mechatronics are addressed, discussing how mechatronics is typically taught around the world also illustrating the trends and applications of mechatronic engineering and research. This is followed by an outline of the necessary skills a mechatronic engineer need to posses and a discussion of control engineering being a key element in mechatronics, where the well established methods from control engineering form very powerful techniques in both analysis and synthesis of mechatronic systems. With basis in this discussion, it is addressed how a mechatronic education is structured so courses and projects are aligned, to utilize the full benefits of the Problem Oriented Project Based Learning (POPBL) system practiced at Aalborg University (AAU). This is followed by a presentation of the two complementary educations in Mechatronics at AAU, describing course outline and project content of the different semesters, where also the thoughts behind the organization of the curricula are addressed. Finally the paper summarizes with an overview of the experiences gained at AAU with teaching mechatronics in a Problem Oriented and Project Based Learning environment.

Keywords: Education, Mechatronics, Control, Problem Oriented and Project Based Learning, PBL

I INTRODUCTION

Since its emerging in the late 1960's the words *Mechatronic* and *Mechatronics* have been associated with a number of different interpretations or definitions, starting with the mixture of mechanical and electronic components to form a mechatronic system. Over the years this conceptions has evolved, and today the general conception is that mechatronics is not just the combination of mechanical and electronic parts to form a product, it is *a synergistic combination of primarily Mechanical, Electrical and Control Engineering in the design of intelligent products and processes*. Synergism and integration in the design phase, is in this way what sets apart a mechatronic system from a traditional, multidisciplinary system, [15, 6, 13, 1, 5, 2]. Mechatronics is hence a very interdisciplinary undertaking, where knowledge from different domains have to be integrated optimally. From an education standpoint the challenge therefore not only lie in teaching the students the basic fundamental courses, but just as much in having them learn the synergistic process in mechatronic design, which largely comes from experience. The latter also being complicated by the circumstance that there is still a large lack in theories, models and tools that facilitate combined modeling, simulation, analysis, synthesis, prototyping and optimization of multi-technological and mechatronic systems. When planning mechatronic educations it is therefore important that the curriculum is designed, so the student obtains experience with all part of the mechatronic design process.

This paper addresses two complementary educations in Mechatronics – the *Mechatronic Control Engineering (MCE)* and the *Electro-Mechanical System Design (EMSD)* educations, both taught at Aalborg University and both utilizing the Project Oriented and Project Based Learning (POPBL) approach, cf. section III. Both being mechatronic educations with a strong focus on design and control of mechatronic systems and the interaction of technologies. But where the EMSD engineers focus highly on designing both mechatronic and mechanical systems, the MCE engineers excels within advanced control engineering. Both educations are however, build around the same thoughts and ideas about how mechatronics is best taught and around a strong constructive alignment of courses and project activities to best control the learning process. The paper is organized as follows. Section two discusses the current trends in mechatronic education, how control engineering is the binding element and how mechatronics should be taught. Section three describe the Problem Oriented and Project Based Learning (POPBL) approach practiced at AAU, and why this is well suited for mechatronic educations. Finally section four and five describe the two mechatronic educations at AAU and summarizes on the experiences gained.

II Teaching Mechatronics or Learning Mechatronics?

Traditionally mechatronics is illustrated as comprising the four kernel technical areas: mechanics, electronics, software (computer science) and control engineering, as shown in Fig. 1, which comprise the formal knowledge that also make the basis for most engineering educations around the world.

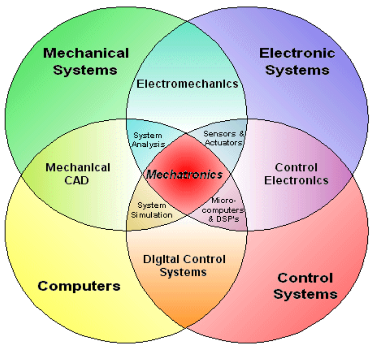

Figure 1: Typical conception of mechatronics.

This follows well in line with the way mechatronic systems most often are developed in industry, where engineering of mechatronic systems and products typically imply a subsystem based approach, where integrated systems are built concurrent from technology homogeneous subsystems (i.e. mechanics, electronics, control and software) and where focus is on the technology interfaces. Once the interfaces are specified, each subsystem is, however, designed in a fairly traditional way. In the subsystem based approach the performance of the mechatronic system is therefore a result of sound integration of existing technology. The same subsystem based approach is often used for educational activities, where fundamental courses are taught, but with only little or no focus on their interaction. The most common pattern in mechatronic education programs and courses are in this way that they originate in mechanical engineering, where courses in electrical engineering, computer science and control engineering are added to make a mechatronic engineering curriculum, but with only little focus on the possible synergies and interaction - the latter typically in the form of one or two courses. The same apply for the other class of educational programs that originate from the computer science, as e.g. the ARTIST initiative [4], which also focus mainly on the formal skills.

As opposed to this subsystem based approach, mechatronics as an engineering science should also focus on the interdisciplinary interactions. However, teaching mechatronics cannot be accomplished by simply adding basic courses, but requires an integrated approach, which combine the kernel disciplines and that also facilitate *modeling*, *analysis*, *synthesis*, *simulation*, *optimization* and *prototyping* (i.e. functional skills) of multi-technological and mechatronic systems. Focus should therefore be just as much on how the students adopts and *learns* these skills and not only on how the basic courses are combined and taught.

One of the programs that try to overcome the above mentioned problems are the CDIO program [7], which is a common educational framework for engineers that: *"provides students with an education stressing engineering fundamentals set in the context of Conceiving — Designing — Implementing — Operating real-world systems and products"* [7], counting at the time of writing 41 universities around the world, among others KHT, Chalmers and LiU in Sweden and MIT in the US, as the founding universities [4]. There is in this program a strong focus on the cross-technological aspects using e.g. project oriented and problem based courses, which practice not only the formal skills but also the functional, but the learning process is centered around the courses and mechatronics is still offered as a master specialization not a complete curriculum [11].

A. Control Engineering as the Binding Element

From the above it should be clear that mechatronics is more than just understanding the kernel disciplines and that the learning process should be structured so the functional skills are also practiced. Figure 2 here shows where the challenges and opportunities arise, due to the integration between disciplines and technologies.

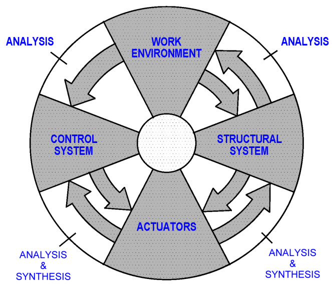

Figure 2: Synergism and integration in mechatronic design.

Taking the subsystem based approach a step further a typical design scenario is that an early conceptual design phase results in a coarse partitioning of functionality between mechanics, actuators and control software, generating a framework for the design. Based on this, an initial mechanical design is generated considering actuator possibilities. This design constitutes the foundation for modeling of the system dynamics, which in turn, provides input to the final actuator selection and control design. The control engineering is here an essential part, not only in the design process, but also in the analysis phase as tools for modeling, analysis, synthesis, simulation and optimization of the system, where the mathematical framework from control engineering comprise the common language for describing and analyzing the system. The use of dynamic models and simulation is in this way the most characteristic feature of mechatronic system design, which is the foundation for analyzing and understanding the interaction between technologies. It is hence the integration of control engineering in the design process, which is the paradigm shift, rather than electronics, as it is also the control system that provides new and extended flexibility and freedom in the design. The requirement is in this connection that the control system is included in the design process from the beginning.

Considering the education aspect, control engineering therefore also plays a central role, as do the other kernel disciplines. Here it is however important to note that control engineering typically is a discipline that takes years to understand and master, i.e. be able to use in a synthesis process, and that this largely comes with experience. Teaching control engineering separately will hence not necessarily enable the student to use this for both analysis and synthesis, but requires a learning environment that facilitates its usage, along with mechatronic courses that focus on the design process, rather than the scientific issues. Concurrently, the students also need to increase their understanding and knowledge of the other kernel disciplines. The correct way to go to obtain this effect is therefore the *problem oriented and project based learning approach*, which offers a number of advantages cf. [12, 9, 10], and which is not be be mistaken for traditional Problem Based Learning (PBL). The benefits of the POPBL approach are here that it makes it possible for the student to get in-depth skills in the area of mechatronics very fast, by combining separate courses in the different technical areas with project work, utilizing the knowledge from the courses and challenging the students to combine this knowledge in interdisciplinary analysis and design. One of the challenges in this approach is, however, to find the balance between technology and methodology, theoretical science versus practical engineering skills and working in teams compared to assessment of the individual students learning performance. The way this is handle is by using constructive alignment, see e.g. [3], to align courses and project theme, as described in the next sections.

III The AAU Model

The education model at Aalborg university (AAU) is generally based around the group based problem oriented and project based learning approach, which has been an integrated part of the university since its founding in the 1970s. For many years AAU has in this way been a pioneer in POPBL and is today well-known for its way of implementing the learning approach. This approach has a number of benefits and disadvantages, but especially for engineering sciences, and mechatronics in particular, this has proven to be a very successful model, cf. the above discussion. In the POPBL approach implemented at AAU the idea is that students are working with specific problems of a nature and complexity, which requires collaboration in project groups and for a duration of one semester, hereby benefiting directly from the collaborative learning environment [4]. To solve the problem the students must put into use the theory they have learned through the class lectures, experimental work etc. and the measurable outcome is a project report, which is the foundation for the evaluation of their work. The process may be illustrated as shown in Fig. 3.

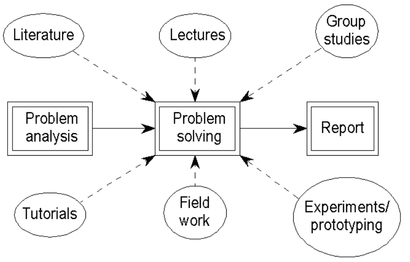

Figure 3: Organization of POPBL process at AAU where lectures, experiments, tutorials, etc. are used as catalysts for the problem solving process.

For this to work properly in a mechatronic curriculum, it do however require careful planning and organization, so the learning objectives, project themes and courses are correctly aligned, but by doing so it is relatively easy to control the learning process, i.e. how and what the students are learning, including how they mix knowledge from different disciplines. The formulation and the content of the project themes are, however, extremely important. The projects in this way work as amplifiers for the intentions of the different semesters and for the whole study curriculum. Each semester has a specific project theme, which is always industry or research related, and the project address problems in relation hereto.

When starting the semester, the project groups are formed, and each group chooses a project among the proposed ones. A project groups normally consist of four to six students, but for master projects the groups are limited to normally one or two students, and at maximum three. Each group is given their own separate offices where they can do their project work, have meetings, solve class exercises etc. and one or more supervisors are assigned each group. The supervisors being active research faculty members. Having determined the project to work on, the students first make a problem analysis, limit the project, and make a time schedule, after which the actual problem solving begins by the use of literature, lectures, group studies, tutorials, field-work and experiments, cf. 3. Practically a semester is typically divided into four periods, see 4. One semester here correspond to 30 ECTS, where the workload include the total time spent on project work and courses. One ECTS is here equal to two-and-a-half days at the university plus time for preparation.

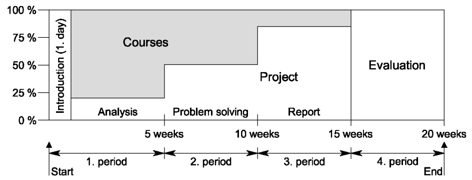

Figure 4: Typical distribution between courses and project work during a semester.

In the first period of a semester the students have a high number of lectures, where many of the fundamental project related courses are given, and the project time is spend on analyzing and properly defining the problem. Three weeks into the semester the problem analysis and a detail time schedule should typically be made. In the second period the number of lectures is slightly decreased, whereas in the third period almost all the time is spent on the project work. The fourth period is allocated for examinations. Considering the daily organization, then a typical day is divided into morning (8.15-12.00) and afternoon (12.30-16.30) slots. In each of the first periods one or two lecture slots are allocated for the project work per week, whereas in the third period almost all time slots are allocated for project work. During a semester the students therefore use approximately half their study time taking courses, and half the time making projects, where they rehearse and utilize the knowledge from the courses.

During the project the supervisor supervises the project work having regular meetings with the students, guide these if they run into problems and ensures that the students keep up to track with the project schedule. At the end of the third period each project group hand in a report (typically 80-120 pages dependent on project and number of students) describing the work of the project, which is also the foundation for the project examination. The project examination is an individual examination, where the student is examined in both the project work and the related courses, and an individual mark is given that reflects the students skills and ability to apply these constructively in the problem solving.

IV Mechatronics at AAU

The above organization is the foundation for the two mechatronic educations at AAU - the Electro-Mechanical System Design (EMSD) education and the Mechatronic Control Engineering (MCE). Both these educations are mechatronic educations in the general sense, but where the EMSD education has been designed on top of a mechanical engineering profile, still with a strong focus on mechanical systems design, the MCE education has been designed from scratch, with a truly multidisciplicary foundation and a stronger focus on control engineering, complete system design and interaction between technologies in the design process. The two educations are hence complementary rather than opposing, although they of course do share the common kernel background. This should also be seen in relation to that the MCE education is initiated based on the experiences from the EMSD education and an even further industry need for mechatronic engineers with a strong control engineering background. It is hence also the same departments (primarily Energy Technology and Mechanical Engineering) and persons that are responsible for the two educations, with the authors being the kernel organizers.

A. Constructive Alignment is the Keyword

Common for both educations is that they are centered around the AAU model for POPBL and that the key element for success in this relation are projects that work as catalysts for the learning process. The requirements for the projects are therefore that they give the students the possibilities for utilizing all the elements they are taught in the courses. At the same time the projects should however also train both the analytical and synthetic skills, give the students experience with experimental work and challenge them to think interdisciplinary. It is therefore of major importance that the projects are related to the courses taught and structured so all elements are included. The way this is handled is by using constructive alignment, where the project themes are designed in correlation with the organization of the courses. On the lower semesters this means that it is the kernel disciplines within an area that are taught, e.g. basic mechanics, machine elements etc. and that the problems primarily relate to design oriented project work, which may be directly solved using the theories, methods and knowledge the students acquire in the lectures. This could e.g. be to design a mobile crane, doing all design considerations, structural and mechanical calculations and analysis and produce technical drawings. On the higher semesters the advanced courses, like e.g. non-linear control theory and optimization theory are taught, and the project focus change to become more interdisciplinary and problem oriented. Here the students may work with problems, for which the solution is unknown up front, and the analysis and synthesis process become more important, as do making the correct technology choices and generally use sound engineering practice. How this is organized for the two curricula is described in the next subsections.

B. EMSD education

As described above the EMSD education is built on top of a traditional mechanical engineering curriculum which afterwards has undergone significant changes to become more mechatronically oriented. The course outline for the EMSD education may be seen in Fig. 5.

In the first year (not included in the overview), called the basic year, the students are introduced to the group work and POPBL and they are taught the basic mathematical and physics courses, along with introductory mechanics and electronics courses. The focus of these semesters are that the students get acquainted with the group based project work and that they learn to address and solve technical problems with basis in theory from the introductory courses.

The third and fourth semesters are fairly traditional mechanical engineering, where the third semester theme is “Process analysis and control” and where the objective is for the students to gain understanding between the function, design, material selection and production process of an industrial product. On the fourth semester focus is instead directed on “Product design”, where the objective is to enable the student to design (and analyze) mechanical systems and products, i.e. do stress and strain calculations, determine machine elements etc. On the fourth semester the student should also begin to gain knowledge about the correlation between various technical fields.

The theme of the fifth semester is “Control system design”, where focus is on applied control theory, and where the objective is that the student obtains skills, which enables him/her to understand, model, analyse and design controllers for dynamic systems. Focus is here also on the interfacing between sensors and actuator, analog and digital implementation of controllers and real-time program execution. The project is in this way the first step in the mechatronics direction. On the sixth semester the theme is “System design”, where an electromechanical system should be designed with focus on parameters as low weight, dynamic performance, control possibilities and material selection. The objective is here that the students learn to systematically design a product and elaborate on the knowledge, which they have gained from the three previous semesters.

3th semester	4th semester	5th semester	6th semester	7th semester	8th semester
Mathmatics 1 (2 ECTS)	Actuation (2 ECTS)	Analytical math and numerical methods (3 ECTS)	Probability and statistics (2 ECTS)	Analogue control II (1 ECTS)	Applied non-linear control (1 ECTS)
Measurement tech. and lab safety (1 ECTS)	Dynamics 1 (1 ECTS)	Analog control theory (2 ECTS)	Robot technology (1 ECTS)	Programming and program development (1 ECTS)	Multivariable control (1 ECTS)
Sequential control (1 ECTS)	Dynamics 2 (1 ECTS)	Digital control theory (2 ECTS)	Design/Redesign (1 ECTS)	Digital signal processors (1 ECTS)	Microcontroller techniques (1 ECTS)
Statics (1 ECTS)	Mechanics of materials (3 ECTS)	Analog electronics II (1 ECTS)	Vibrational theory (2 ECTS)	Electric actuators I (1 ECTS)	Electric actuators III (2 ECTS)
Plastic shaping (1 ECTS)	Element methods (1 ECTS)	Measurement tech. and data acquisition (3 ECTS)	Mechanics II (1 ECTS)	Electric actuators II (1 ECTS)	Design optimisation – concepts and methods (1 ECTS)
Polymer technology (2 ECTS)	Machine elements (1 ECTS)	Thermodynamics (1 ECTS)	Theory of elasticity (1 ECTS)	Hydraulic servomechanisms (1 ECTS)	Design optimisation of mechanical systems (1 ECTS)
Material Science (3 ECTS)		Heat transfer (1 ECTS)	Finite element methods II (1 ECTS)	Fluid kinematics (2 ECTS)	Fracture mechanics I (1 ECTS)
			Economy – investment calculation (2 ECTS)		Fracture mechanics III (1 ECTS)
			Theory of science (3 ECTS)		

Figure 5: EMSD course overview. The colors refer to Fig. 1.

On the seventh semester the theme is "Servo mechanisms and continuum loads", where focus is on control of distributed (continuum) mechanical systems. The he objective is here that the students gain understanding for electrical and hydraulic servomechanism, the influence of the flexible mechanical system and the interaction between the elements. The objective is furthermore that they gain further knowledge about implementing control algorithms and how these may be designed to compensate for and improve system dynamics.

The eight semester focus on "Design and control of power transmission systems", where it is a requirement that the students work with an induction motor. The project aims at how an induction motor works and how this is controlled in a transmission system, using a frequency converter. A large part of the project here deals with the students designing and building a frequency converter or selected parts hereof, along with designing both controllers for the system. The objective of the project is here furthermore that the student understands and practice the innovative process of analysis and synthesis of a mechatronic systems.

Finally on the nine and tenth semester the themes are respectively "Industrial development work" and the master project. On both these semesters the students are free to work within all parts of the mechatronic area, and the projects are typically directly related to ongoing industry projects. The objectives for these two semesters are in this regard for the students to specialize further within selected areas and show their capabilities of solving real world problems.

B. MCE education

As described in the first part of the section the MCE education is designed from scratch, with the central elements in the education being concentrated around control theory, combined with a solid understanding of the basic physical properties and interaction of technologies. The objective of the MCE education is here: "to provide an advanced mechatronic control engineering profile enabling the candidate to analyze, model, design and control energy systems based on a solid understanding of the physical properties of the controlled system and its components. These systems or components being electrical, thermal, fluid- or mechanical systems or any combination hereof." The course outline for the MCE program may be seen in Fig. 6.

As for the EMSD education the first year is a basic year, with largely the same courses and also very broad project scopes. When it comes to the following semesters the diversion however become more distinct. On the third semester the project theme is "Modeling and analysis of energy systems" and the purpose of the semester is for the students to gain knowledge of fundamental electrical and thermo-mechanical systems and experimental work, i.e. basic theories and methods and their applicability and limitations. On the fourth semester the theme is "Control of Energy Converting Systems", where the student is to obtain knowledge and skills within classic linear control theory, when applied to thermo-mechanical and electro-mechanical energy systems. Again focus is largely on being able to develop dynamic models that simulate the system behavior and understand the dynamic properties of the system when applying control laws.

For the fifth and the sixth semester (bachelor) the themes are respectively "Mechatronic system analysis" and "Mechatronic system design". For the fifth semester the purpose of the project is for the student to gain knowledge about the importance of including modeling and control in the design process for mechatronic systems, and for the stu-

3th semester	4th semester	5th semester	6th semester	7th semester	8th semester	9th semester
Mathematics I (2 ECTS)	Mathematics II (2 ECTS)	Analytical mathematics and numerical methods (3 ECTS)	Probability theory and statistics (2 ECTS)	Non-linear control theory (2 ECTS)	Robust feedback control (2 ECTS)	Stiff systems and diff. algebraic equations (1 ECTS)
Modeling (1 ECTS)	Applied control engineering (2 ECTS)	Mechatronics I (2 ECTS)	Mechatronics 2 (1 ECTS)	System identification (1 ECTS)	Modelling and control of robot manipulators (1 ECTS)	Linear optimal control (1 ECTS)
Electromagnetic circuits (1 ECTS)	Power electronics I (2 ECTS)	Digital signal processing (1 ECTS)	Mechatronics 3 (1 ECTS)	Control of AC machines (1 ECTS)	Advanced control of AC drives (1 ECTS)	Advanced non-linear control (2 ECTS)
Fundamental circuit theory (2 ECTS)	Data acquisition (1 ECTS)	Microcontrollers (1 ECTS)	State-space control (1 ECTS)	Switch Mode DC/DC converters (1 ECTS)	Applied digital signal processor (1 ECTS)	Adaptive control (1 ECTS)
Fundamental AC-circuit theory (1 ECTS)	Dynamics (1 ECTS)	Digital electronics (1 ECTS)	Discrete control theory (1 ECTS)	Hydraulic and pneu. comp. and systems (2 ECTS)	PLC automation (1 ECTS)	Linear electric actuators (1 ECTS)
Analog Electronics (1 ECTS)	Mechanics of materials and vibration analysis (2 ECTS)	3-phase AC circuit theory (1 ECTS)	Dynamic models of electrical machines (2 ECTS)	Advanced mechanics (2 ECTS)	Power electronics (2 ECTS)	Project study courses (selectable) (min. 2 ECTS)
Measurement techniques and laboratory safety (1 ECTS)	Fluid flow and heat transmission (2 ECTS)	Steady-state analysis of electrical machines (2 ECTS)	Finite element method (1 ECTS)	Scientific English (1 ECTS)	Optimisation theory (2 ECTS)	
Statics (1 ECTS)	Energy and economics (1 ECTS)	Hydraulics (1 ECTS)	Project management, contract and economy (2 ECTS)		Innovation and Entrepreneurship (2 ECTS)	
Heat conduction (1 ECTS)		Material science (1 ECTS)	Theory of science (2 ECTS)			
Thermodynamics (1 ECTS)			Energy and the environment (1 ECTS)			
Engines and turbines (1 ECTS)						

Figure 6: MCE course overview. The colors refer to Fig. 1.

dent to understand the need for an analysis process that incorporates thinking about systems dynamically. The objective is furthermore that the student gain understanding for digital controller design and implementation. On the six semester focus is instead shifted so it is on the student acquiring knowledge about how to design mechatronic systems and components. This is especially in relation to being able to evaluate different solutions and their suitability, also when considering the interaction of different technologies and their limitations in the design process. After obtaining the bachelor degree, the student should in this regard be able to design basic mechatronic systems and components, be able to analyze and assess different technical solutions, and have knowledge about mechatronics as a design process and philosophy.

For the seventh and eight semester the content correspond very much to that of the EMSD education. The theme of the seventh semester is "Control of hydraulically or pneumatically actuated mechanical structure" and the objective is to enable the students to describe and control mechanical structures with complex dynamics and non-linear behaving elements. This includes using system identification methods for determining unknown dynamics and applying selected non-linear control method on the considered system. On the eight semester focus is again shifted more towards electrical machines, where the theme is "Advanced control of electrical machines" and the objective is to give the student comprehension of applied vector control strategies, robust control theory and enable the students to design controllers for induction motors. The students should furthermore obtain knowledge about the operating principles of inverters and be able to design subsystems hereof.

On the nine and tenth semester the project themes are more broad. The theme on the ninth semester is "Intelligent control of energy systems", where the objective is to enable the student to control intelligent complex energy systems utilizing advanced non-linear controllers. The students should in this relation also evaluate the performance, the methods and technologies in relation to the system design. As for the EMSD, the tenth semester is for the master project for which there is no theme. The objective of the project work is here to enable the student to document his/her obtained skills and the level at which he/she is able to exploit these skills in solving a specified task.

B. Experiences Gained

Where the EMSD has been running since 1998 and the first graduates emerged in 2001, the MCE program is still new, with the first students first coming through the program, why experiences are primarily based on the EMSD candidates. The general experience with candidates from AAU and the POPBL learning environment is that the candidates produced are more readily adaptable for research and for industry, and thus more directly employable,[8]. Recent studies among danish industrial companies have in this connection shown that the candidates from AAU are generally considered the most applicable, and the engineering educations at AAU are the best in Denmark, [14]. In the general perspective graduates coming from a more traditional systems may be better grounded in the fundamentals, and are more capable of working individually, but lack the experience and interdisciplinarity related to most work and hence generally require more on the job training. For the mechatronic area, there is however no competition for the POPBL approach, where interdisciplinarity and synergistic combination of different technologies are the key elements, and where the students gain experience, which they otherwise could not get on university. This also reflects in the mechatronic engineers coming from AAU, which are among the most ask for engineers and which finds jobs in all areas of the industry.

V Summary & Conclusion

This paper addressed the general challenges related to teaching mechatronics, and how it may be taught utilizing the benefits from the problem-oriented project based learning approach. The paper first addressed the educational challenge of mechatronics, which require solid knowledge from both the mechanical, electrical, computer and control technical fields, and it was described how control engineering may be seen as the binding element, where the mathematical tools related to control theory form a strong foundation for modeling, simulation, analysis and synthesis of mechatronic systems. From this discussion the problem-oriented and project based learning approach utilized at AAU was presented and it was described, why this learning environment form a very strong foundation for the teaching mechatronics. Finally the two complementary mechatronic educations at AAU were presented, describing their content, structure and thoughts behind the organization, and it was described how all projects extensively use simulation and control theory methods when analyzing and designing complex commercial systems of a strongly dynamic nature. The courses and project themes for the educations are in this way planned to facilitate the students optimal learning of mechatronics.

References

[1] T.O. Andersen, M.R. Hansen, and F. Conrad. An approach to design of power mechatronic systems. In *Mekatronikdag 2003, R&D teams making mechatronic products and system solutions, Technical University of Denmark*, 2003.

[2] T.O. Andersen, H.C. Pedersen, and M.R. Hansen. Mechatronic system design based on an optimisation approach. In *Mechatronics Day 2007 - International Workshop on Mechatronics, DTU, Copenhagen*, DTU, Copenhagen, Apr. 2007.

[3] J. Biggs. *Teaching for Quality Learning at University, Second Edition*. Open University Press, McGraw-Hill Education, 2003. ISBN: 0 335 21168 2.

[4] Martin Grimheden. *Mechatronics Engineering Education*. Doctoral thesis, KTH School of Industrial Engineering and Management, Sweden, KTH School of Industrial Engineering and Management SE-10044 Stockholm Sweden, 2006.

[5] M.R. Hansen and T.O. Andersen. Project-oriented and problem-based learning: A mechatronic curriculum. In *Proc. IMECE 2004: International Mechanical Engineering Congresss and R&D Expo, Anaheim, CA*, Anaheim, California, USA, Nov.14-19. 2004. ASME, ASME.

[6] J.R. Hewitt. Mechatronics - the contributions of advanced control. In *Proc. 2nd Conference on Mechatronics and Robotics*, Duisburg, Germany, 1993.

[7] The CDIO Initiative. http://www.cdio.org.

[8] F. Kjaersdam and S. Enemark. *The Aalborg Experiment - Project Innovation in University Education*. Aalborg University Press, 1994. ISBN: 87-7307-480-2.

[9] E. Laursen. Selvstyret læring - udviklet gennem iscenesatte forløb (in danish). Aalborg University, Denmark, 1998.

[10] P.F. Laursen. Hvad er forskningsbaseret undervisning? (in danish). *Undervisningsministeriets Tidskrift: Uddannelse*, 8, 1996.

[11] KTH School of Industrial Engineering and Management. http://www.kth.se/itm?l=en_uk.

[12] R.C. Pettersen. *Problembaseret læring*, chapter Problembaseret læring eller undervisning (in Danish). Dafolo, 1999.

[13] D. Shetty and R.A. Kolk. *Mechatronics System Design*. PWS Publishing Company, 1997.

[14] Bjørn K. Sørensen. Aalborg Universitet lammetæver DTU på nytænkning. *Ingeniøren*, May 2009.

[15] H. van Brussel. The mechatronics approach to motion control. In *Proc. Int. Conf. on Motion Control - The Mechatronics Approach*, Antwerp, Belgium, 1989.