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Mechatronics Engineering Education

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Abstract

Since its emergence in the late 1960s, mechatronics has become well-established as an academic subject, and is now researched and taught at a large number of universities worldwide. The most widely-used definition of the subject today is centered on the synergistic integration of mechanical engineering, electronics, and intelligent computer control.

The aim of this thesis is to work between the disciplines of engineering education and mechatronics to address both the question of the identity of the subject of mechatronics and the ways in which this identity can be reflected in the practice of mechatronics education.

Empirical data from the literature is supplemented with further data from four case studies with approaches varying from exploratory case studies and ethnographic in-depth studies to explanatory studies with an action research based approach.

The process and results of the investigation can be divided into three aspects. Firstly, analysis of the subject of mechatronics shows that its identity is thematic and its legitimacy is functional, implying that the selection and communication of the subject ought to be exemplifying and interactive respectively. Secondly, and following this analysis, the concept of international collaboration is used as the implementation for the first two case studies. The results of these studies show a relationship between collaborative projects and enhanced disciplinary learning and skills, increased awareness of cultural differences, and improved motivation. Another potential implementation, experimental learning, is then tested in two action research based studies focusing on fast prototyping and individual access to laboratory equipment.

Mechatronics is a special subject, not easily understood or taught. To be mechatronic is to be synergistic, and to be synergistic generally demands expertise in all underlying subjects. The conclusion of this thesis is that this requires a non-traditional education where the focus is on training rather than studying, coaching rather than teaching, experimenting rather than reading, working together rather than apart, and being mechatronic rather than studying mechatronics.

Keywords: mechatronics, thematic subject, synergy, engineering education, international collaboration, experimental learning, didactical analysis

Sammanfattning

Mekatronik som ämne uppstod under 1960-talets senare del och har sedan dess etablerats som akademiskt ämne som beforskas och undervisas på ett stort antal universitet runt om i världen. Den idag mest utbredda definitionen av ämnet fokuserar på synergi och synergistisk integration av maskinteknik, elektronik och intelligent datorstyrning.

Målsättningen med denna avhandling är att bidra till forskning i området mellan de två fälten ingenjörsutbildning och mekatronik. Forskningsfrågan behandlar identiteten hos ämnet mekatronik och hur denna identitet kan återspeglas i undervisningens praktik.

Empiriskt material för denna avhandling har hämtats från litteraturen tillsammans med fyra fallstudier. Forskningsmetodiken i fallstudierna har varierats från utforskande fallstudier och etnografiska djuplodande studier till förklarande studier med en aktionsforskningsansats.

Studien och resultaten därutav kan delas in i tre delar. Den första delen behandlar ämnet mekatronik och visar att ämnets identitet är tematisk och att legitimiteten är funktionell. Detta innebär att ämnets selektion och kommunikation bör vara exemplifierande respektive interaktiv. I den andra delen används denna definition för studier av internationellt samarbete i mekatronik, vilket utgör basen för de två första fallstudierna. Resultaten från dessa studier visar på en relation mellan det internationella samarbetet och ett ökat disciplinärt lärande, ökad medvetenhet om kulturella skillnader samt en ökad motivation. Den tredje delen relateras till ytterligare en tänkbar implementation av definitionen, en idé om experimentellt lärande. Denna prövas i två studier baserade på aktionsforskning som behandlar snabb prototypframställning och individuell tillgång till avancerad laborationsutrustning.

Mekatronik är ett speciellt ämne, inte helt enkelt att förstå eller undervisa. Att vara mekatronisk innebär att vara synergistisk, och att vara synergistisk kräver vanligtvis expertkunskap i de underliggande områdena. Resultatet av denna avhandling är att detta kräver en icke-traditionell undervisning där fokus är på träning snarare än studerande, handledning och guidning snarare än undervisning, experimenterande snarare än läsning, arbete tillsammans snarare än individuellt och att vara mekatronisk snarare än att studera mekatronik.

Nyckelord: mekatronik, tematiskt ämne, synergi, ingenjörsutbildning, internationellt samarbete, experimentellt lärande, didaktisk analys

There's nothing like the sound of scraping of chairs.

Robert Meyer (1936-2004)
On the occasions when his lectures at KTH were so popular that the students had to drag in more chairs.

Contents

Preface

I wish to express my gratitude to the following people for their contribution to the work that this thesis is based on:

- Main supervisor: Mats Hanson
- Supporting supervisor: Helge Strömdahl
- Mentors: Sören Andersson and Robert Meyer
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Stockholm November 22, 2005,

Martin Grimheden

List of appended papers

The papers included in this thesis are grouped in three categories according to their scope. The papers included in the final two categories are built upon the results of those in the first category.

The subject of mechatronics

Paper A

What is Mechatronics? Proposing a Didactical Approach to Mechatronics
Martin Grimheden and Mats Hanson
Proceedings of the 1st Baltic Sea Workshop on Education in Mechatronics, 20–22 September 2001, Kiel, Germany.

Paper B

What is Embedded Systems and how should it be taught? — Results from a didactical analysis
Martin Grimheden and Martin Törngren
ACM Transactions on Embedded Computing Systems, Vol. 4, No. 3, pages 633–651, 2005.

Paper C

Mechatronics — the Evolution of an Academic Discipline in Engineering Education
Martin Grimheden and Mats Hanson
Mechatronics, Vol. 15, pages 179–192, 2005.

International collaboration

Paper D

Collaborative Learning in Mechatronics with Globally Distributed Teams
Martin Grimheden and Mats Hanson
The International Journal of Engineering Education, Vol. 19, No. 4, pages 569–574, 2003.

Paper E

The Challenge of Distance: Opportunity Learning in Transnational Collaborative Educational Settings
Martin Grimheden and Helge Strömdahl
The International Journal of Engineering Education, Vol. 20, No. 4, pages 619–627, 2004.

Paper F

International Collaboration in Mechatronics Education
Martin Grimheden
Proceedings of the 5th International Workshop on Research and Education in Mechatronics, REM2004, 1–2 October 2004, Kielce, Poland.

Experimental learning

Paper G

A modular approach to experimental learning and fast prototype design of mechatronic systems — introducing the mechatronic learning concept
Martin Grimheden and Mats Hanson
Proceedings of the International Conference on Engineering Design, ICED03, 19–21 August 2003, Stockholm, Sweden.

Paper H

Providing a framework for prototype design of Mechatronic systems — A field study of an international collaborative educational project using the Mechatronic Learning Concept
Martin Grimheden and Mats Hanson
Proceedings of the 3rd International Workshop on Education in Mechatronics, REM2002, 26–27 September 2002, Copenhagen, Denmark.

Paper I

The Lab in Your Pocket — A modular approach to experimental learning in Mechatronics
Martin Grimheden and Mats Hanson
Proceedings of the International Conference on Mechatronics, ICOM03, 19–20 June 2003, Loughborough, United Kingdom.

Statement of co-authorship

Papers A and C were co-authored by Hanson, who contributed background material, research ideas, and discussion of the methods and results. Grimheden collected the data, wrote the papers and carried out the analysis.

Paper B was co-authored by Törngren, who provided background material and contributed to the text by providing the industrial context and the embedded systems perspective. Grimheden wrote the majority of the paper and carried out the analysis in discussion with Törngren.

Paper E was co-authored by Strömdahl, who participated in several interviews, focus groups, and observations. This paper was mainly written by Grimheden, but the analysis was carried out during intensive discussions with Strömdahl.

Papers D, G, H, and I were co-authored by Hanson. These papers were written by Grimheden, with Hanson acting as supervisor.

Additional publications

Theses

Learning Mechatronics — In Collaborative, Experimental and International settings. Licentiate Thesis in Machine Design
Martin Grimheden
Dep. of Machine Design, Royal Institute of Technology, Stockholm, Sweden. TRITA-MMK 2002:20, ISSN 1400-1179, 2002.

Variationer i teknologers problemlösning. En empirisk studie av några problemlösningsativiteter och problemlösningsmetoder på KTH. (Variations in student approaches to Problemsolving. An empirical study of problemsolving-activities and problemsolving-methods at the Royal Institute of Technology, In Swedish.), B.Sc. Thesis in Education
Martin Grimheden
Department of Education, Stockholm University, 1999.

Conference proceedings

How should embedded systems be taught? Experiences and snapshots from Swedish higher engineering education, invited paper and presentation
Martin Grimheden and Martin Törngren
Proceedings of the Workshop on Embedded Systems Education, WESE2005, 22 September 2005, New Jersey, USA.

Coaching Students into the Concept of Design Engineering
Martin Grimheden, Sofia Ritzén and Sören Andersson
Proceedings of the International Conference on Engineering Design, ICED05, 15–18 August 2005, Melbourne, Australia.

What is Design Engineering and how should it be taught? — Proposing a Didactical Approach
Martin Grimheden and Mats Hanson
Proceedings of the International Conference on Engineering Design, ICED05, 15–18 August 2005, Melbourne, Australia.

Teaching Fast Prototype Design of Mechatronic Systems — From idea to prototype in 24 hours
Martin Grimheden and Mats Hanson
Proceedings of the 6th International Workshop on Research and Education in Mechatronics, REM2005, 30 June – 1 July 2005, Annecy, France.

Design as a social activity and students' concept of design
Martin Grimheden and Sören Andersson
Proceedings of the International Engineering and Product Design Education Conference, 2–3 September 2004, Delft, The Netherlands.

How might Education in Mechatronics benefit from Problem Based Learning?
Martin Grimheden and Mats Hanson
Proceedings of the 4th Workshop on Research and Education in Mechatronics, REM2003, 9–10 October 2003, Bochum, Germany.

The Mechatronics Collaboration Project between KTH and TTU (Sweden–Estonia)
Martin Grimheden, Avo Kask, Raivo Sell and Mart Tamre
Proceedings of the 3rd European Workshop on Education in Mechatronics, 25–27 September 2002, Copenhagen, Denmark

Technical reports

Maskinkonstruktion — Sociala konstruktioner av ingenjörers maskiner (Machine Design — Social Constructions of Engineers Machines, In Swedish)
Martin Grimheden
TRITA-MMK 2004:04, ISSN 1400-1179, 2004.

Vad är Maskinkonstruktion, och hur skall det undervisas? (What is Machine Design, and how should it be taught? In Swedish)
Martin Grimheden (ed.)
TRITA-MMK 2004:03, ISSN 1400-1179, 2004.

Chapter 1

Introduction

This thesis addresses the subject of mechatronics in the context of higher education in engineering. Mechatronics emerged in the literature during the late 1960s and is now researched and taught as an academic subject in universities throughout the world. During its almost 40-year lifetime, the subject has evolved through a series of redefinitions from the original concept of electrification of mechanisms to its current definition, which is based on the concept of synergy.

> "The synergistic integration of mechanical engineering with electronics and intelligent computer control in the design and manufacturing of industrial products and processes" (Harashima et al., 1996).

The quotation above, by Harashima, Tomizuka and Fukuda, represents a milestone in this evolution. It was published in the first issue of the journal IEEE/ASME Transactions on Mechatronics, where the editors presented it as a new definition of mechatronics.

Another milestone, in the evolution of mechatronics in the academic community in Sweden, is illustrated by an anecdote that describes the birth of mechatronics at KTH, the Royal Institute of Technology in Stockholm. Jan Schnittger, professor in machine elements, returned to KTH in 1976 from a visiting professorship at Stanford University. He brought with him an Intel 8008 microcontroller, declaring that it should be considered as a machine element. Today, almost 30 years later, the Mechatronics Lab constitutes one of the larger research teams within the School of Industrial Engineering and Management at KTH.

Even though most mechatronicians are content with this definition, there still exist lively discussions regarding the next steps in the evolution of the subject — *what will come after this?* Opinions are quite diverse, but there are strong tendencies toward an expanded concept of synergy, for example the synergistic integration of mechatronic systems networks, or the development of conscious systems that require the encompassment of areas such as biology (Cotsaftis, 2002).

1.1 Aim and scope

The aim of this thesis is to help bridge the research gap between the area of engineering education and the specific subject of mechatronics. This is accomplished by beginning with an analysis of the subject of mechatronics according to current research in the area of subject matter education, and then implementing the results of that analysis — firstly in the context of international collaboration and secondly using the experimental approach to learning — and examining the outcome of these implementations.

Finally, using the definition of mechatronics presented above, and keeping in mind current discussion related to the evolution of the subject of mechatronics, the essential questions considered are:

> What is special about the academic subject of mechatronics, and how should one study and teach it? Is the subject really special at all, and is it really necessary to treat this field differently from others?

1.2 Research contribution

A substantial amount of research has been performed in the field of engineering education, most of it during the last couple of decades. Areas such as engineering education, collaborative learning, international collaboration, and experimental approaches have been thoroughly researched, but rarely in the context of an applied engineering subject such as mechatronics. This is mainly because most academics choose to specialize in one field, either education or engineering, and attempts to bridge this gap are seldom found. Educational research is often considered by the educational establishments to be difficult to understand and hard to implement, and so is commonly dismissed as irrelevant.

Since most engineering researchers also teach in their particular fields, it is not surprising that mechatronics researchers often take a great interest in mechatronics education. However, despite the large body of research in engineering education, there are very few researchers specializing in mechatronics engineering education. The main contribution of this thesis is to fill a little more of the void between the faculties of mechatronics engineering and the existing research in engineering education, most of which has been performed by educational researchers rather than mechatronicians.

The subject of mechatronics

The analysis of the subject of mechatronics presented in this thesis provides a deeper understanding of the nature, history, and establishment of the subject, a state-of-the-art analysis of current teaching in mechatronics in northern Europe, and a model for the development of the subject that can be used to facilitate the development of mechatronics education at a university level.

Further, this analysis offers answers to the questions of what is mechatronics, and why should it be taught, and develops these answers to address the question of how it should be taught.

International collaboration

Additional contributions to the fields of distributed learning, collaborative learning, and international collaboration are provided by the results and conclusions of experiments performed in mechatronics education with globally-distributed student teams. Highlights of these findings include evidence of both enhanced disciplinary learning and improvements in complementary skills, results consistent with the conclusions of the analysis described above.

Experimental learning

This application of the results of the subject matter analysis contributes primarily by offering a framework for experimental learning that incorporates portable laboratory equipment and fast prototype design. The concept is introduced and evaluated on two occasions, in two different settings, and among the results are signs of enhanced disciplinary learning, improved motivation, and lower educational cost to the faculty.

1.3 Structural outline

This thesis comprises eight introductory chapters along with three sets of appended papers. Each set contains three papers dealing with a particular aspect of mechatronics engineering education. The introductory chapters are outlined in Table 1.1, and the relationship between this introductory section and the appended papers is described in Figure 1.1 and Table 1.2.

Of the introductory chapters, the first three and the last conform to the traditional design of introduction, theoretical framework, methodology, and conclusions.

Chapter four, Current trends in engineering education, presents a state-of-the-art analysis of engineering education with a focus on the changes that are currently occurring. This analysis is based on a study of the literature.

Chapters five to seven are all based on performed experiments, and provide the main thrust of the thesis; firstly a didactical analysis of the subject of mechatronics, and then the results of two categories of implementations of some concepts stemming from this analysis.

1.4 Summary of appended papers

Each of the three sets of appended papers relates to one of chapters five to seven, as set out below.

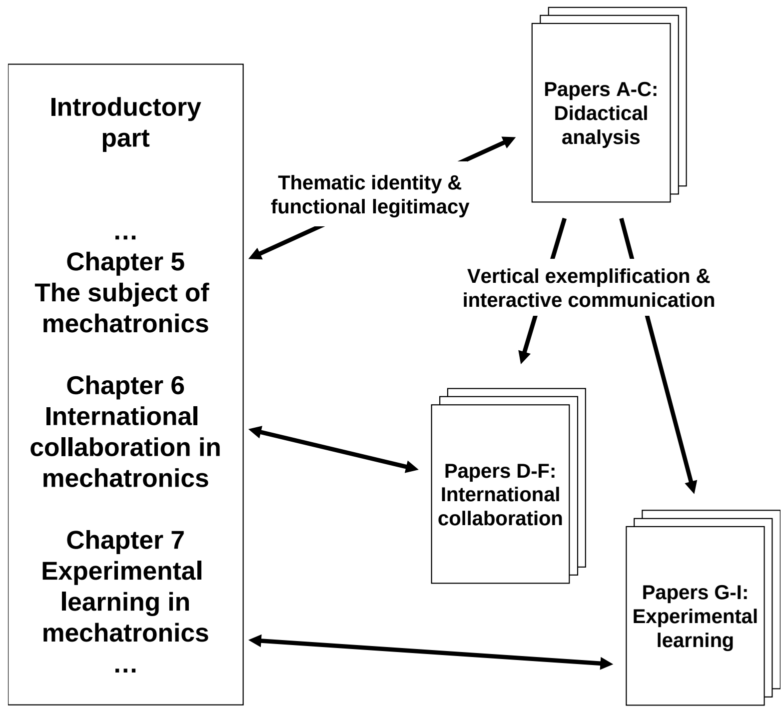

Figure 1.1: The outline of the thesis and the relation between the introductory part and the papers

The subject of mechatronics (chapter 5 and papers A–C)

The didactical approach aims to analyze and describe a specific subject in terms of four questions, or dimensions — identity, legitimacy, selection, and communication. The didactical analysis of the subject of mechatronics is introduced in section 2.1 and then presented fully in chapter 5 and papers A–C.

Paper A: What is Mechatronics? Proposing a Didactical Approach to Mechatronics

This paper introduces the didactical approach, as used in this thesis, and applies it to the subject of mechatronics. A variety of empirical data is used; the history of mechatronics education at KTH, a survey performed in 1999 covering 65 courses at 34 universities, and an evaluation of the mechatronics master program at KTH performed in 1996.

The paper concludes that mechatronics as a subject has a thematic identity and a functional legitimacy and would benefit from being taught with an exemplifying selection and with interactive communication.

Paper A was submitted in March 2001, accepted for publication in August 2001, and published and presented in September 2001.

Table 1.1: Outline of introductory part of thesis

Chapter	**1**
Title	Introduction
Chapter	**2**
Title	Theoretical framework
Chapter	**3**
Title	Methodology
Chapter	**4**
Title	Current trends in engineering education
Description	State-of-the-art analysis, background descriptions of related areas
Chapter	**5**
Title	The subject of mechatronics
Description	Results and discussion
Chapter	**6**
Title	International collaboration
Description	Results and discussion
Chapter	**7**
Title	Experimental learning
Description	Results and discussion
Chapter	**8**
Title	Conclusions

Table 1.2: Outline of the appended papers of the thesis and their relation to the introductory part

Title	**The subject of mechatronics**
Chapter	5
Appended papers	A–C
Title	**International collaboration**
Chapter	6
Appended papers	D–F
Title	**Experimental learning**
Chapter	7
Appended papers	G–I

Paper B: What is Embedded Systems and how should it be taught? — Results from a didactical analysis

The second paper performs the same analysis as the first for the subject of embedded systems. This paper is based on empirical data gathered in a study of 21 Swedish companies dealing with industrial software engineering.

The results of paper B are in line with those of paper A. This is unsurprising, since the subject of embedded systems has strong ties to the subject of mechatronics, and could perhaps even be considered to be a subset of mechatronics. As well as showing that the subject of embedded systems follows the same educational pattern as that of mechatronics, this study provides further evidence for the thematic identity and functional legitimacy of mechatronics.

Paper B was submitted in October 2004, accepted for publication after modifications in March 2005, and published in August 2005.

Paper C: Mechatronics — the Evolution of an Academic Discipline in Engineering Education

The final paper in this set follows up the didactical analysis presented in paper A by introducing a model for the evolution of a subject with a thematic identity.

The model is illustrated by and verified with material gathered primarily from studies of mechatronics programs and efforts at establishing mechatronics as an academic subject in northern Europe.

This paper provides yet more evidence to establish the thematic identity and functional legitimacy of the subject of mechatronics, and concludes that the introduced model can be used to understand and predict the evolution of the subject.

Paper C was presented at a conference in October 2001 and submitted in May 2002. It was then resubmitted unchanged in April 2003, accepted for publication after modifications in July 2004, and published in March 2005.

International collaboration (chapter 6 and papers D–F)

Papers A–C suggest that the subject of mechatronics would benefit from being taught with an exemplifying selection and an interactive communication. Papers D–I explore this further by focusing on two methods of implementation; international collaboration and experimental learning.

One conclusion of the analysis already described is that mechatronics education should be functional, focusing on the capability to develop mechatronic products in industry. Such capability relies strongly on not only interdisciplinary knowledge, but also on complementary skills such as aptitude for teamwork, leadership proficiency, and effective communication. The international collaboration outlined in papers D–F is concerned with the introduction of these skills into mechatronics education and ways of coping with the difficulties that this imposes on students and faculty.

Paper D: Collaborative Learning in Mechatronics with Globally Distributed Teams

This paper deals with the difficulties related to teaching mechatronics with globally distributed teams. It presents a field study of two consecutive educational projects performed in 2000–2002 involving two sets of student teams in each project; two each at KTH in Stockholm, Sweden and at Stanford University, USA.

The results suggest that an international collaborative setup provides possibilities for students to enhance both their disciplinary skills and their knowledge and skills in complementary areas as well as increasing their awareness of cultural differences and enhancing their motivation.

Paper D was submitted in February 2002, accepted for publication after modifications in December 2002, and published in August 2003.

Paper E: The Challenge of Distance: Opportunity Learning in Transnational Collaborative Educational Settings

Paper E uses the same empirical data as paper D to provide an in-depth focus on three areas already identified as problematic in distributed educational settings. Where the previous paper gives a broad overview of primarily the disciplinary learning in the distributed setting, this paper uses the same data to analyze how the student teams coped with and managed difficulties related to distance in time and space.

The main thrust of this paper is the presentation of several examples of difficulties that were turned into challenges by the students, primarily those difficulties related to distance in time and space, and those challenges which could be used as opportunities for learning if handled appropriately by students and faculty.

Paper E was submitted in March 2002, accepted for publication after modifications in December 2003, and published in August 2004.

Paper F: International Collaboration in Mechatronics Education

The third and last paper in this section presents a summary of five years of international collaboration in mechatronics education along with specific experiences from those involved.

The data is based on field studies performed during the five years of collaboration as well as previously published papers in this area.

Its conclusions are primarily that different collaborative settings promote different skills; either general experience of working in international settings and preparation for future careers in such areas, or promotion of the cross-disciplinary and cross-boundary student collaboration that has already been shown to be beneficial for the subject of mechatronics.

Paper F was submitted in July 2004, accepted for publication in September 2004, and published and presented in October 2004.

Experimental learning (chapter 7 and papers G–I)

A second conclusion of the didactical analysis of the subject of mechatronics is that an experimental approach to learning can foster both an interactive communication and an exemplifying selection. The experimental approach can enable students to focus deeply on one specific project and enable them to work in teams as well as individually.

The three papers in this section all present results of an attempt to introduce a concept for experimental learning in mechatronics — the mechatronic learning concept.

Paper G: A modular approach to experimental learning and fast prototype design of mechatronic systems — introducing the mechatronic learning concept

This paper introduces the mechatronic learning concept and attempts to provide motivation for its use in mechatronics education.

Some preliminary results are included in the paper, primarily showing that the project is feasible and most likely advantageous. The results are gathered from two implementations, one in a basic course in microcontroller systems and one in an advanced course in mechatronics.

An abstract of paper G was submitted in September 2002 and a full paper in February 2003; this was accepted for publication after modifications in May 2003 and presented and published in August 2003.

Paper H: Providing a framework for prototype design of mechatronic systems — a field study of an international collaborative educational project using the mechatronic learning concept

Paper H presents a field study of a large scale implementation of the use of the mechatronic learning concept in a regular course in mechatronics. The study explains how prototype design and manufacturing was facilitated by the concept, and how the students' design process was enhanced by the mechatronic learning concept.

Paper H was submitted in August 2002 and accepted, published, and presented in September 2002.

Paper I: The lab in your pocket — A modular approach to experimental learning in mechatronics

The final paper describes an experiment in which the mechatronic learning concept was introduced in a basic course in microcontroller systems. The empirical data was gathered both quantitatively in questionnaires and qualitatively in interviews.

The results show that the mechatronic learning concept, or the 'lab in your pocket', provides an individual approach for the students as well as a mobile accessibility which can increase students' ambition for, knowledge of, and skill in the subject of mechatronics.

An abstract of paper I was submitted in June 2002 and a full paper in February 2003 which was accepted for publication after modifications shortly thereafter. The paper was presented and published in June 2003.

Chapter 2

Theoretical framework

Research in education usually focuses on one of three different levels; an individual level (educational psychology), a classroom or subject level, or a societal level (educational sociology). This thesis uses the societal level only in passing, in order to understand the evolution of the subject of mechatronics at a university level. The individual level is considered when studying the impact of the educational efforts, meaning the individual learning process. This level is used to understand how the learning processes occur, and to see the connection between the efforts undertaken on the classroom, or subject, level.

Educational studies on the scale of a group of students, for example a class, and the relation between the efforts undertaken by the teacher or university and the class are usually referred to as didactical studies, at least in central Europe and the Nordic countries (Kansanen, 1995), see also Figure 2.1. Most research in the field of didactics aims at describing the unique properties of the subject of interest and setting out how that particular subject ought to be taught (Dahlgren, 1990).

(It should be noted that in Anglo-Saxon countries the phrase ‘subject matter

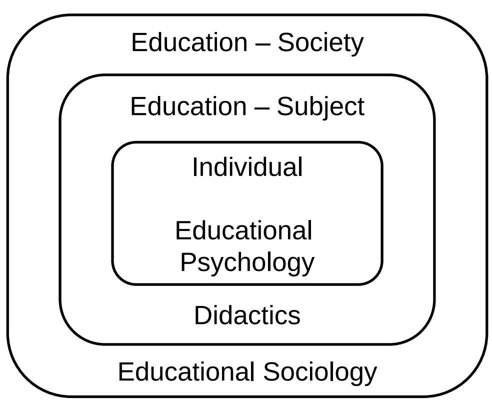

Figure 2.1: The three dimensions of educational research. From Dahlgren (1990)

education' is preferred, and the term 'didactics' is more commonly used in a completely different sense to mean "texts overburdened with instructions and facts" (Encyclopaedia Britannica, 2005); in this thesis, didactics should be understood as being synonymous with subject matter education.)

2.1 The didactical approach

The term *didactics* emerged in the literature at the beginning of the 17th century, and was at that time synonymous with the German word 'Lehrkunst', meaning 'the art of learning'. One of the first users of the term was John Comenius, in his 1657 publication Didactica Magna (Comenius, 1999). Originally the idea of the didactic field was that all teaching required its own methods and that every discipline had its own system and followed its own logic. If, through research, this logic could be determined, then the appropriate teaching method would be that of presenting the disciplinary contents according to the disciplinary logic. Subsequently, the didactical researchers started to uphold the general didactic principle that education is actually discipline-independent and follows its own logic. Even though subject didactics dominates today, it is still a valid subject of discussion whether the preferred approach should be the general or the subject didactics. Since the 17th century, the area of didactics has evolved from the original idea of encompassing all educational aspects to focus on particular knowledge and skills (Alerby et al., 2000).

As explained earlier the term 'subject matter education' is used in some countries to mean didactics, or, rather, subject didactics. In German and Swedish, the word 'didaktik' has more or less the same meaning. In English literature the use of the word 'didactics' is less common, and even though the definition as used in this thesis has already been clarified, there is a need to further press the original meaning of 'didaktik' (Kansanen, 1995). Hudson et al. (1999) proposes that the term cannot be understood without the concept of 'bildung' in German or 'bildning' in Swedish, an idea that can perhaps be translated as creation, formation, or erudition. The concept of bildung encompasses social context, the shaping of the personality, and the interaction of the learning process with previous knowledge and experience, as well as interaction with others. It also encompasses cultural aspects, as well as social interaction, and is not limited to certain subjects, ages or situations. Didactics, as used in this thesis, can therefore be defined as "the science whose subject is the planned support of learning to acquire *bildung*" (Hudson et al., 1999).

When turning from general didactics to subject didactics the same definition can be used, but instead of matters relating to the educational process in general, the focus is on matters that relating to the content of a particular subject.

Dahlgren (1990) proposes that a didactical analysis of a subject can be based on three categories, or questions. The number of questions, and the questions themselves, varies according to origin and interpretation, but in this thesis the three categories given by Dahlgren are used with the addition of a fourth, the question of identity — see Figure 2.2.

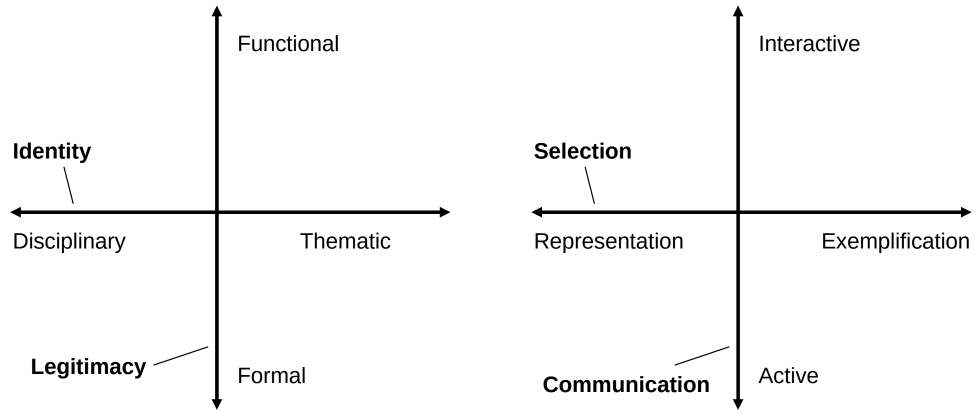

Figure 2.2: The four didactical questions, partly adapted from Dahlgren (1990)

The first question is concerned with identity. A subject's identity can be classified as either disciplinary or thematic. This classification is not difficult to make, and it is perhaps more revealing to study changes of identity within a specific subject. As new topic areas are introduced and the evolution of knowledge in a particular subject moves forward, the classification of its identity usually changes from the thematic identity of a newly-created subject to slowly settle into the disciplinary identity of a more mature one. This process is exemplified by cross-disciplinary subjects such as systems engineering and cognitive science. These usually originate from a theme — systems and cognition respectively, in these examples — which runs through a series of other subjects like mathematics, philosophy, and psychology. The subject of systems engineering would be classified as thematic, but the subject of mathematics as disciplinary.

The next question, according to Dahlgren, is the question of legitimacy. This question is connected to the relationship between the actual outcome of the educational efforts and the nature of the demand that is put upon the student's abilities by society, or by industry. This demand is categorized into two aspects, either formal or functional, and the relation between the outcome and the nature of the demand is thus related to either formal legitimacy or functional legitimacy. In a simplified model, the formal aspect deals with formal knowledge, that which is commonly found in textbooks and is intended to be read and understood by students. The functional aspect deals with those skills which are not usually learnt in textbooks or during lectures but are developed with hands-on exercises, during laboratory experiments, or by trial and error. To give an example, a foreign language course could focus on either the ability to correctly spell words or the ability to communicate. The societal demands could either be formal, for example specifying which words the students should be able to spell correctly, or functional, requiring that students should be able to accomplish such tasks as ordering a beer at the München Oktoberfest.

In this thesis a distinction is made between the preceding two questions and the two following, with the hypothesis that the questions of identity and legitimacy strongly affect the answers to the questions of selection and communication.

The question of selection within a subject can be viewed in the perspective of two extremes. The more traditional standpoint takes the view that the content selected to teach a subject should be representative, giving a broad perspective over the entire subject. The opposite extreme is provided by the practice of exemplification, in which the subject is exemplified rather than represented. These two viewpoints are often described as horizontal and vertical, respectively. For example, in the subject of computer science a horizontal representation would be a curriculum spanning the entire field, with students being taught knowledge and principles relating to computer science in general. A vertical, exemplifying selection would be one in which a single computer platform or language was studied to a much greater depth. The underlying philosophy of vertical exemplification is that the knowledge and skill relating to, for example, one particular language can be carried over to facilitate learning of other similar languages; however, this is certainly not an uncontested theory.

Finally, the question of communication can also be described by using two extremes. Firstly, if teaching is considered as action, the question of communication is a question of such things as how the teacher should act in relation to the subject to be understood, how the teacher should act toward the students, and so on. On the other hand, from the perspective of interaction, the important action is that based on feedback; action from the teacher based on output from the students, or action based on insight into the current learning processes of the individual students.

Summary of the four didactical questions

The didactical analysis of an academic subject, as defined by Dahlgren, can be illustrated with a set of four questions applied to a subject (X).

Identity (What is X?)
: Identity varies from disciplinary to thematic.

Legitimacy (Why should X be taught?)
: Legitimacy varies from formal to functional.

Selection (Which X should be taught?)
: Selection varies from a horizontal representation to a vertical exemplification.

Communication (How should X be taught?)
: Communication varies from active to interactive.

2.2 Approaches to learning

When given an assignment, a piece of homework, or some similar exercise, different students approach the same task in different ways. These differences in approach were thoroughly researched in the 1970s and are commonly described as deep and surface approaches to learning (Marton et al., 1984). Students were asked to read a text, and were then asked questions relating to it. Differences in the students' answers were explained with the notion that different students simply approached the task differently; the students created different intentions for the task, and those who approached the task with a 'deep' intention 'learned more' than the other students. The question, however, is how didactics can support the deep approach when most educational systems usually promote the surface approach, for example by focusing on details instead of the overall picture (Marton and Säljö, 1976a,b). A student who perceives a task to be meaningful usually adopts a deeper approach. Such meaning can stem from a larger educational picture, be understood in relation to a future professional role, or simply be motivated by a clearer explanation of the purpose of performing the task.

A similar analysis of approaches to learning, or rather of student understanding, was performed by Bloom, who identified three educational domains, or types of learning: cognitive, affective, and psychomotoric. The cognitive domain relates to mental skills, or knowledge, the affective domain to feelings and attitude, and the psychomotoric domain to manual and physical skills (Bloom et al., 1964). Further, each domain is divided into a number of categories, where each category represents a level of understanding or knowledge, and where each must be mastered before moving on to the next. The six categories of cognitive knowledge and intellectual skills are (Bloom et al., 1964):

Knowledge To recall data, recite text, quote figures etc.

Comprehension To understand the meaning, to state a problem in one's own words.

Application To use a concept in a new situation, to apply knowledge to situations in, for example, the workplace.

Analysis To separate material and concepts into parts to enable understanding of organizational structure, to troubleshoot by use of techniques such as logical deduction.

Synthesis To build a structure from separate and diverse components, to form a whole by creating new meaning and structure.

Evaluation To judge the value of ideas and materials.

Variants of Bloom's taxonomy have been suggested by various authors, for example the seven levels of engagement presented by Biggs (2003), which model the variations in a student's engagement from memorizing to theorizing.

When studying Bloom's taxonomy a parallel can be made to the theories of tacit knowledge and the different types of knowledge, for example as introduced by Wittgenstein (1933) or von Wright (1971), and to the idea that advancement in the categories presented by Bloom requires knowledge and skill not easily explained or communicated, instructed or shown. Researchers such as

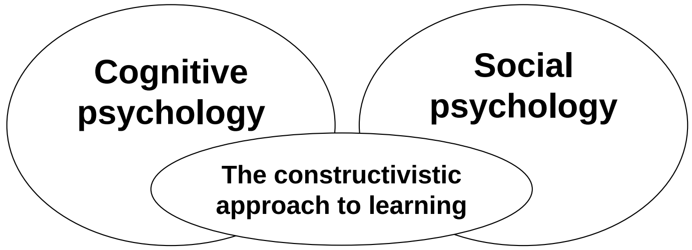

Figure 2.3: The constructivist approach to learning is based on research undertaken partly within cognitive psychology and partly within social psychology (Piaget, 1972; Vygotsky, 1987)

Göranzon (2001) have shown in practice how approaches such as a 'master-apprentice setting' can facilitate advancement in knowledge and skill, with the hypothesis that this is dependent on tacit knowledge, and that tacit knowledge can primarily be learnt by experience; see for example Hoberg (1998).

To summarize, the key questions when discussing what to teach and how to teach it are how to promote deep approaches to learning and how to climb the six steps of knowledge within the cognitive domain.

2.3 A constructivist approach to learning

The constructivist approach to learning is based on research in both cognitive psychology and social psychology, and has its roots within the epistemological questions Immanuel Kant faced during the late 18th century; questions based on the relationship between objects in the so called outer world and individuals' awareness of such objects (see Figure 2.3).

The modern approach to constructivist learning is primarily based on research undertaken by John Dewey, Jean Piaget and Lev Vygotsky during the first half of the 20th century (Dewey, 1933; Piaget, 1929; Vygotsky, 1987; Eggen, 1999). The constructivist theory of knowledge, as developed by Piaget, can be summarized into the following principles:

- a person constructs his knowledge on the basis of his experiences;
- knowledge is not equal to empirical sensory impressions;
- knowledge is not equal to inner rational reasoning, independent of sensory impressions;
- knowledge is a mental tool for understanding reality, and is constructed in the interaction between sensory impressions and reason;
- knowledge is (inner) cognitive structures that a person constructs through active interaction with the (outer) world.

The theory separates learning into dynamic and structural aspects. The dynamic aspect deals with the driving force of learning, and its origins, while the structural aspect deals with the content and nature of learning. Piaget describes learning as a process of adaptation and balancing in which the individual attempts to keep its internal representation of its surroundings in equilibrium with its experiences. One part of this balancing is provided by the process of assimilation, in which sensory impressions are added to existing structures of knowledge — a kind of additive learning. The complementary process, accommodation, encompasses the ways that the individual adjusts its mental model to fit its surroundings. Equilibrium is maintained by these two processes, assimilation and accommodation, working in combination.

An example may help to illustrate the individual constructivist approach as outlined by Piaget [1]. A teacher is introducing the subject of geometry to a class of eight-year-old pupils. The teacher draws a square box on the blackboard, points to one corner, and declares "This is a corner". When one of the pupils hears this, he makes an association (consciously or unconsciously) with the corners of the rooms at home. The constructivist approach to learning considers that the pupil has now expanded his definition of the term 'corner'. Before, a corner was a corner in a house, or a street corner, but now it can also be the point where the lines that form a square meet. The pupil has assimilated an empirical sensory impression into his pre-existing structure of knowledge. To maintain the process of equilibrium, the balance, the pupil's existing structure of knowledge has changed, through accommodation, and been adapted to include the new definition. The characteristics of the constructivist approach to learning are primarily this constant assimilation and accommodation between existing structures of knowledge and the surroundings.

Learning according to Piaget

The learning theories developed by Piaget are based on adaptation and equilibrium:

Adaptation Two techniques of adaptation exist: assimilation and accommodation. Adaptation is defined as the tendency to adjust to the environment. The individual strives to use adaptation to remain in balance with its surroundings.

Assimilation Humans assimilate and organize observations and sensory impressions into coherent sets of meanings; this process makes the thinking process more effective. Assimilation is the easiest technique of adaptation, being used in situations where new observations fit fairly easily into existing structures.

Accommodation When new observations or sensory impressions don't fit neatly into existing structures of knowledge, these structures have to be

[1] This example is adapted from a presentation given by Professor Inger Wistedt, Department of Education, Stockholm University.

changed. It is not a matter of the earlier structures being right or wrong, simply that they must change in order to accommodate the new observations and impressions.

Equilibrium Equilibrium is defined as the process in which the individual strives to retain balance between existing structures and new observations by way of adaptation, either assimilation or accommodation. This process, according to Piaget, is the learning process.

The constructivist approach described above is referred to in literature as individual constructivism (Marton and Booth, 2000). It is not the same thing as social constructivism, an approach based on the psychology developed by Vygotsky (1987). Social constructivism, unlike individual constructivism, focuses on outer actions as explanations for inner reasoning instead of the other way around. Vygotsky describes child development as the change from a biological nature to a social one, and the key to understanding learning in a social constructivist approach is the concept of mediating, or pre-interpretation. In contradiction to the individual constructivist approach, where human development in terms of knowledge is determined by inner reasoning in relation to the surroundings, the social constructivist perspective is that development is dependent on the interpretation into common and collective human activities.

To summarize the social constructivist approach: all human acts are situated in a social practice. The acts of an individual always originate from the individual's knowledge and experience, and in particular from what the individual consciously or unconsciously understands about the demands of, or allowances made by, its surroundings (Säljö, 2000).

2.4 Problem based learning

Problem based learning (PBL) originated at the Case Western Reserve University Medical School in U.S., and was established as an accepted method of teaching medicine primarily at McMaster University Medical School in Canada during the 1960s. According to Vernon and Blake (1993), by 1993 more than 80% of medical schools were using PBL as their preferred teaching method.

In a typical PBL setting the work of the students (and faculty) is organized into projects, each of which aims at solving a particular problem. PBL can be discipline-specific or case-based, or, preferably, a combination of both. The learning environment is characterized by greater responsibility being given to the students, and by mutual trust, respect, and helpfulness. The faculty and its members have a coaching role instead of a lecturing one.

A common discussion subject within the PBL community is the relationship between the acquisition of sufficient knowledge — both basic and specific — and the application of this knowledge; a relationship that could also be described as being between knowledge and skill. Even if PBL does not merge these two processes completely, the intention is to integrate them, or at least not separate them completely as is often the case in more traditional education.

The basic ideas behind problem based learning are the following (Grimheden and Hanson, 2003b; Vernon and Blake, 1993):

Active learning Students should be given opportunities to actively participate in their education; for example, traditional one-way lectures should be replaced with more interactive learning opportunities such as seminars, group work, and projects. Interaction, dialogue, and discussion are key.

Constant assessment Immediate feedback between students and teachers is necessary for active learning. Also of importance is that constant assessment of the educational process should be performed by the faculty, both to improve courses and to give students a feeling of involvement in their education.

Emphasis on meaning and not facts PBL is not intended to facilitate the memorizing of large quantities of data, but rather to foster understanding of contextualized problems.

Freedom and responsibility Students should be given more freedom regarding both their schedules and their approaches to a given problem; they should essentially be made responsible for their own learning. Vernon (1995) has shown that this generally produces more self-motivated and independent students.

Access to resources Many aspects of traditional lectures can be replaced by information resources. Central to every PBL course are the library — the hub of information — and the skills to find the required information.

Project based learning

In the literature, the acronym PBL is most often used for problem based learning, but sometimes also for project based learning. Project based learning is most commonly used to describe the organization of the teaching activities, for example that students occupied with problem based learning as educational method can be organized into projects, or that the problem solving activities are performed by students in a project-like setting.

2.5 Product based learning

Product based learning can be seen as a subset of either project based learning or problem based learning. Both concepts are used; students are organized into projects, and faced with a problem - that of designing a product.

Figure 2.4 illustrates a model for the phases of product based learning developed by Leifer from the ideas of Kolb (1984), Harb et al. (1993), and his own research (Leifer, 1995, 1998).

The idea is that students learn in four different ways, and that repeated cycling through these learning modalities facilitates the learning process and helps to bridge the gap between theory and practice (Kolb, 1984). A student

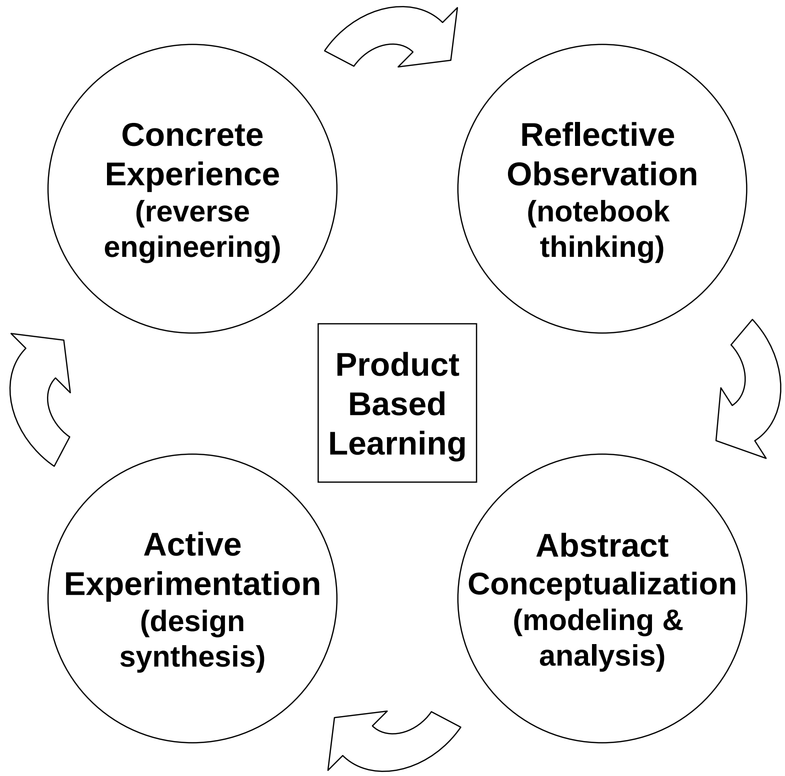

Figure 2.4: The four-phase-loop of experimental learning, from Leifer (1998)

project aimed at product development is an ideal implementation of this since product development is an iterative process. An entire curriculum or course can be based on this idea, with the students being coached into processing through repeated cycles with the use of an appropriate product development model, for example one in which they are required to iteratively create a number of prototypes on their route to the final deliverable. The challenge for the faculty is to support, encourage, and facilitate the reflective phase and the abstract conceptualization phase since these phases are often quickly discarded by students eager to leap into the active experimentation phase.

Where other related teaching methods such as problem based learning or project based learning focus on the problem or project, product based learning is unique in that it makes a connection to an industrial reality — the product. Where methods such as problem based learning are sometimes seen as training exercises, product based learning, according to Leifer (1995), focuses the attention on developing something of value, something suitable for evaluation by others. This industrial relevance not only offers the potential for increasing student motivation but also the possibility of attracting corporate sponsors.

Bridges and Hallinger (1995) have expanded on the basic principles of problem based learning to lay out the objectives of a PBL curriculum which provides relevance for product based learning in the context of a product design education:

- familiarize students with problems inherent in their future profession;
- assure content and process knowledge relevant to these problems;
- assure competence in applying this knowledge;
- develop problem formulation and problem solving skills;
- develop implementation skills;
- develop skills to lead and facilitate collaborative problem solving;
- develop skills to manage emotional aspects of leadership;
- develop and demonstrate proficiency in self-directed learning skills. (Bridges and Hallinger, 1995)

2.6 Collaborative learning

According to a recent analysis of engineering design thinking, teaching, and learning by Dym et al. (2005), project based learning is the most-favored pedagogical model in universities today, and is most commonly implemented in the form of cornerstone courses (first year courses) and capstone courses (final year courses).

Dym et al further provide a connection between the legitimacy of the subject of design engineering (related to the ability to design a system, component or process to meet certain needs) and learning as a social activity, via constructivist theories of learning (Minneman, 1991). The cornerstone and capstone courses are seen as opportunities to improve students' abilities to work in teams, as well as their communication skills.

One important aspect inherent in project based learning is collaborative learning. Collaborative learning has been extensively studied in research fields such as education, psychology, and computer science (Dillenbourg, 1999). A commonly used definition of collaboration is the one introduced by Roschelle and Teasley (1995):

> "... a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem"

Dillenbourg (1999) uses the following three aspects of learning to describe and define collaborative learning:

The collaborative learning situation

A learning situation is more likely to be of a collaborative nature if:

1. the participants are all of equal status; for example, all students rather than a mix of students and teachers;

2. each participant is equally skilled, and each is allowed to perform the same actions as any other;

3. the participants have a common goal, and;

4. the participants work together to reach their goal (Dillenbourg, 1999).

The first two aspects, equality of status and equality of skills and action, have been described as the symmetries of a learning situation (Dillenbourg and Baker, 1996; Ligorio, 1997). A fully-collaborative situation firstly requires complete symmetry of action, primarily in that all participants should be allowed to perform the same types of actions Dillenbourg and Baker (1996). Secondly, symmetry of knowledge is necessary; all members should possess an equal level of knowledge and understanding. The final requirement is symmetry of status, where status is defined as the relative standing perceived and determined by the surrounding community (Ligorio, 1997).

The importance of a common goal, a shared meaning, and interaction between the participants is summarized in the definition of collaborative learning suggested by Barfurth (1995):

> "Collaboration involves the construction of meaning through interaction with others and can be characterized by a joint commitment to a shared goal."

Collaborative interaction

Interaction between participants in a learning situation is more likely to be of a collaborative nature if it is characterized by discussion rather than, for example, giving instructions. Collaborative interaction is built on negotiation and discussion, and is unlikely to flourish in hierarchical situations where people use authority rather than rational reasoning to impose their ideas and views on others. Dillenbourg (1999) uses the term 'negotiability' to characterize an interactive educational setting; negotiating is preferred to imposing, negotiation is the preferred method of interaction between members, and the setting should provide time, space, and a suitable environment for negotiation.

In short, the aspect of symmetry can also be applied to the interactive setting; negotiation on equal terms provides a safe space in which people can argue their ideas using rational reasoning.

Collaborative aspects of learning mechanisms

Collaboration in itself implies social interaction, which as shown in section 2.3 is fundamental to learning. In the constructivist approach, the internalization process is the process of transfer from the social plane and the surroundings to the inner plane and individual reasoning. Returning to the example of the child and the corner, the internalization process is what happens when the child suddenly makes the connection between the physical corners in rooms and the meeting point of two lines.

It is possible to see that a symmetric and interactive context is beneficial for the internalization process, in other words, the interaction between the social plane and the inner plane can be increased by the symmetrical setting and constant negotiation of a collaborative educational situation.

In other words, since knowledge is created by interaction with the outer world (Piaget, 1929), the learning mechanism of internalization benefits from a collaborative setting.

2.7 Learning as a social activity

John Dewey wrote in 1922 that in order to revitalize the American public, schools would have to become "the dangerous outposts of a humane civilization" and "begin to be supremely interesting places" (Boydston, 1976).

For the American public, this era also saw the birth of new, progressive schools and universities where the focus was on cooperative work and programs to prepare students for lifelong cooperative work. The idea was to make the universities into "supremely interesting places" by, for example, introducing learning as a social activity (Coleman, 2001).

In a comparison between engineering subjects related to design, synthesis and product development and more traditional academic subjects such as mechanical engineering or electrical engineering, a didactical analysis gives that one possible approach to integrate complementary skills such as teamwork skills is to treat the subject as a social activity, which, according to the identity and legitimacy of the subject, would be advantageous by way of providing the overall picture of the professional role as product development engineer to the students. To treat engineering education as a social activity is then a way of showing students how engineers work.

Teaching mechatronics engineering as a social activity implies a need for collaboration. This collaboration manifests itself in three ways: teamwork between students and faculty and between the university and industry or society; openness toward other students, the university, and society; and interest from all participants (Hennessy and Murphy, 1999; Rogoff, 1990; Cross and Clayburn, 1995).

Learning as a social activity is slightly different from collaborative learning in that it expands the view from the symmetrical group to encompass additional actors such as the faculty, the university, and the surrounding society.

2.8 Summary

The didactical analysis of the subject of mechatronics uses the concepts of identity, legitimacy, selection, and communication to answer the questions of what, why, and how — what is mechatronics, why should it be taught, and how should it be taught. This thesis addresses the questions of what and how.

The constructivist approach to learning focuses on the relationship between inner reasoning and cognitive structures, and interaction with the outer world. It places emphasis on the ways in which cognitive structures are constantly adapted to accommodate new experiences and discoveries, and new objects and phenomena are assimilated into existing cognitive frameworks.

Problem based learning and product based learning are examples of educational settings that, from a constructivist viewpoint, are better than more traditional ones because of their emphasis on a higher degree of student activity, freedom, and responsibility.

Interaction with the outer world is fundamental to both the constructivist approach and the principles of problem and project based learning. The concept of collaborative learning is closely connected to such interaction. Collaborative learning is grounded in the idea of symmetry; symmetry of knowledge, status, and goals are all required to produce not a hierarchical group of people who communicate by instruction but a collaborative group of peers who communicate by negotiation.

Chapter 3

Methodology

Research methodology varies greatly, especially between fields as diverse as education and applied engineering. In studies of learning in higher education the most commonly used research methods are case studies, ethnographic studies, action research, and surveys, while in applied engineering research, tools such as experiments and correlational research are also common. The purpose of this chapter is to introduce the reader to the main research methods used in this thesis. Most of these can be classified as qualitative methods, but since paper I uses a quantitative approach, quantitative methods are briefly described here as well.

One difficulty of moving between different research methods is that people working in different fields, with different backgrounds and traditions, often have preconceived ideas that can lead to misunderstanding. Research in higher engineering education, for example, sometimes relies on the Aristotelian method of deductive reasoning, in which logical deductive evidence and hard statistical data express the only truths. Learning in mechatronics is not easily quantified, and the effects of mechatronics education cannot be captured as a numerical change in a variable.

The method of inductive reasoning, introduced by Francis Bacon in the 1600s, addresses some of the problems of the deductive approach. Most researchers today accept a combination of deductive and inductive reasoning, for example as formulated by Mouly (1978), where he defines the inductive-deductive approach as:

> "a back-and-forth movement in which the investigator first operates inductively from observations to hypotheses, and then deductively from these hypotheses to their implications, in order to check their validity from the standpoint of compatibility with accepted knowledge. (...) This dual approach is the essence of the modern scientific method and marks the last stage of man's progress toward empirical science."

When comparing the approaches mentioned and considering the difference between deductive and inductive reasoning, two broad categories emerge — approaches aiming at creating theoretical frameworks that can be tested by experimentation, and approaches aiming at understanding and interpreting the world. A third approach, which takes political and ideological contexts into account and is often referred to as critical educational research, has also been identified in the literature. See, for example, Cohen et al. (2000). This third approach is not addressed here.

3.1 Case studies

A case study is “the study of an instance in action” (Adelman et al., 1980). The instance could be a class or an international community, and the purpose of the case study is to study real people in real situations (Cohen et al., 2000).

The case study can also be designed to illustrate a more general principle (Nisbet and Watt, 1984). Case studies can establish cause and effect, and can penetrate situations in ways that are not susceptible to numerical analysis (Adelman et al., 1980). The concept of case studies is further investigated and defined by Hitchcock and Hughes (1995), and summarized by Cohen et al. (2000) into the following identifiers:

- a case study is concerned with a rich and vivid description of events relevant to the case;
- it provides a chronological narrative of events relevant to the case;
- it blends a description of events with the analysis of them;
- it focuses on individual actors or groups of actors, and seeks to understand their perceptions of events;
- it highlights specific events that are relevant to the case;
- the researcher is integrally involved in the case;
- an attempt is made when writing up the report to portray the richness of the case.

Yin (1984) identifies three types of case studies, in terms of their outcomes:

- exploratory case studies, as pilots to other studies or research questions;
- descriptive case studies, to provide narrative accounts, and;
- explanatory case studies, to test theories.

In literature, different authors define different types of case studies. When combining ideas from Cohen et al. (2000), Stenhouse (1985) and Merriam (1988) the following list of types can be compiled:

- ethnographic case studies, single in-depth studies;
- action research studies;

Table 3.1: The case studies referred to in this thesis, and their relations to the appended papers

Case	**Mucca**
Instance	Mechatronics advanced course
Time	Dec. 1999 – June 2000
Presented in	Papers D & E
Case	**Company**
Instance	Mechatronics advanced course
Time	Oct. 2000 – June 2001
Presented in	Papers D & E
Case	**Boston**
Instance	Mechatronics advanced course
Time	Oct. 2001 – June 2002
Presented in	Papers G & H
Case	**Lab in your pocket**
Instance	Basic course in microprocessor systems
Time	Jan. 2002 – June 2002
Presented in	Papers G & I

- evaluative case studies;
- educational case studies;
- other types such as historical, psychological, and sociological.

Further, observations can be undertaken in two different ways; participant observation or non-participant observation. Looking at these in terms of the deductive and inductive approaches, in deductive reasoning there is advantage in keeping the number of variables controllable, and so the non-participatory approach would be the obvious choice. However, most educational researchers agree that the non-participatory approach is impossible to achieve in practice, and could even be considered unethical since it would require that the individuals studied be unaware of the observer.

Case studies in the appended papers

Case studies have been used as the primary research methods in papers D, E, G, H and I. These five papers are based on four separate case studies. Table 3.1 presents the case studies and states when they were performed and in which papers they are used.

The three first case studies (Mucca, Company and Boston) were all based on a setting where the researcher had a solely researching role and was not involved in the actual teaching of the course. In the fourth case (lab in your pocket) the researcher had an assistant teaching role as well as a researching role. In terms of earlier discussion regarding participation, the researcher had a participating role in all four case studies, but a more neutral role, for example

Table 3.2: Primary research methods used in the case studies presented in the appended papers

Appended papers	**A–C**
Type of case study	No case studies
Aim of study	
Characteristics	
Appended paper	**D**
Type of case study	Exploratory case study
Aim of study	Pilot study
Characteristics	Researcher had a participating role
Appended paper	**E**
Type of case study	Descriptive case study
Aim of study	Presents narrative accounts of studied activities and phenomena
Characteristics	Ethnographic approach in data collection Researcher had a participating role
Appended paper	**F**
Type of case study	No case studies
Aim of study	
Characteristics	
Appended paper	**G**
Type of case study	Exploratory case study
Aim of study	Pilot study
Characteristics	Action research based Researcher had a participating role
Appended paper	**H**
Type of case study	Descriptive case study
Aim of study	Presents narrative accounts of results from an experiment
Characteristics	Action research based Researcher had a participating role
Appended paper	**I**
Type of case study	Descriptive and Explanatory case study
Aim of study	Presents accounts and quantitative measurements from an experiment
Characteristics	Evaluative Researcher had a participating role

in terms of teaching and grading the students, in the first three and more the role of a teacher in the fourth.

These four case studies were performed according to the definitions made by Yin (1984), for two different purposes and in two different modes, as pilot studies or as descriptive case studies; see Table 3.2. In other aspects, the case studies conformed to the identifiers of Cohen et al. (2000), as mentioned above.

3.2 Ethnography

Ethnography is an active method of research in which the researcher captures and documents people's experiences by way of observing and participating in their lives (Kullberg, 1996). The researcher observes people's actions, listens to their discussions, and studies how these actions and discussions change with time and place. An ethnographic study is characterized by the following:

Field study The ethnographic study is often referred to as a field study. The basic principle is that the researcher spends a considerable amount of time in the environment of those studied.

Interviews Interviews are performed, in the form of either in-depth interviews or informal interviews or discussions.

Collecting artifacts Traditionally the researcher collects artifacts and documents related to the field and their artifacts. This is more relevant to some research areas, for example the study of foreign cultures, than others, for example educational research.

Documentation The researcher uses a number of techniques for documentation — notes, for example in the form of a log or a diary, recordings of audio and video, email, and so on.

In contrast to the case study, the field study or ethnographic study is based on the continuous analysis of data and artifacts, even if a final concluding analysis also is performed.

The basic idea of ethnographic studies is that the research is performed in everyday environments and contexts. The ethnographic approach is often referred to as a naturalistic approach, meaning that everything is studied in its natural context (Cohen et al., 2000; Kullberg, 1996).

Hitchcock and Hughes (1995) use the following list of characteristics to describe ethnographic approaches to research in education. According to them, ethnography involves:

- the production of descriptive cultural knowledge of a group;
- the description of activities in relation to a particular cultural context from the point of view of the members of that group or culture;
- the production of a list of features constitutive of membership in a group or culture;
- the description and analysis of patterns of social interaction;
- the provision as far as possible of 'insider accounts';
- the development of theory.

Ethnographic studies in the appended papers

In the studies presented in the appended papers an ethnographic approach was taken in one study, presented mainly in paper E. In contrast to the case studies used in some of the other papers, the study presented in paper E is based on a thorough data collecting phase and uses observations and audio and video recordings to produce narrative accounts of the phenomena, or types of activities, studied.

In this study each student was interviewed twice, and all material produced by the students for the project was collected. The case study 'Company' is therefore presented both as an exploratory case study in paper D and as an ethnographic case study in paper E. The reason behind this is that paper D only deals with the preliminary findings of the study, and not the full set of data used in the analysis of paper E.

In this ethnographic study the approach introduced by Hitchcock and Hughes (1995) is used. Narrative descriptions of the patterns of social interaction within the groups, as defined by Hitchcock and Hughes (1995), provide examples of the implementation of this approach, and serve to illustrate the communicational intensity between the student teams and faculty involved in the project.

3.3 Action research

Action research is defined by Cohen et al. (2000) as:

> "a small-scale intervention in the functioning of the real world and a close examination of the effects of such an intervention."

Somekh (1995) argues that action research is designed to bridge the gap between research and practice and to overcome the persistent failure of research to impact on practice, by combining diagnosis with reflection and by focusing on practical issues (Cohen et al., 2000).

Winter (1996) proposes six key principles of action research, quoted below:

- reflexive critique, the process of becoming aware of our own perceptual biases;
- dialectical critique, the way of understanding the relationships between the elements that make up various phenomena in our context;
- collaboration, the principle that everyone's view is taken as a contribution to understanding the situation;
- risking disturbance, the understanding of our own taken-for-granted processes and the willingness to submit them to critique;
- creating plural structures, the development of a number of accounts and critiques rather than a single authoritative interpretation;

- theory and practice internalized, the perception of theory and practice as two interdependent yet complementary phases of the change process.

Action research is performed in two stages: the diagnostic stage where the problems are analyzed and hypotheses developed, and a second stage where the hypotheses are tested by an intervention or experiment (Cohen et al., 2000). Lewin (1946) has identified four phases of action research: planning, acting, observing, and reflecting.

A number of contributors to the literature emphasize the importance of the democratic principles that form the basis of action research, and the necessity for a free flow of information between participants and researchers. Morrison (1998) sets out the following necessary conditions for a setting appropriate for action research:

- participatory approaches to decision-making;
- democratic and consensual decision-making;
- shared values, beliefs and goals;
- equal rights of participation in discussion;
- equal rights to determine policy;
- equal voting rights on decisions;
- shared responsibility and open accountability;
- judgments and decisions based on the power of the argument rather than the power or status of the advocates;
- shared ownership of decisions and practices.

Action research approaches in the appended papers

As shown in Table 3.2, an action research approach was used in two papers; G and H. The interventions that these papers are based on were performed in two separate courses at KTH using an action research based approach and active participation (see Table 3.3). The following arguments demonstrate that the conditions of action research proposed by Morrison (1998) are fulfilled.

In both cases a relatively small group of students were subjected to the study, twelve students in the Boston case and twenty in the ‘lab in your pocket’ case. In both studies the students were informed of the research activities ahead of time; in the Boston case, during the course but prior to the stage where the intervention was made (i.e. the introduction of the equipment for fast prototyping) and in the ‘lab in your pocket’ case, prior to the actual course. In the ‘lab in your pocket’ case the participating students actively chose to participate in the study, while in the Boston case the students were given the option of whether to use the equipment or not.

In the ‘lab in your pocket’ case the students were motivated to participate in the study by being informed that their experiences and suggestions would be

Table 3.3: Overview of action research studies and their relations to the appended papers

Case	**Boston**
Instance	Mechatronics advanced course
Action	Implement fast prototyping
Time	Oct. 2001 - June 2002
Presented in	Papers G & H
Case	**Lab in your pocket**
Instance	Basic course in microprocessor systems
Action	Introduce individual laboratory equipment
Time	Jan. 2002 - June 2002
Presented in	Paper G

beneficial in future versions of both the course and the laboratory equipment. All students were also given the option of dropping out of the experiment and transferring to the traditional 'regular' course.

3.4 From methods to tools

The previous sections mainly dealt with research methods. In the following sections the focus will be on tools for data collection rather than the underlying research method. An overview of the empirical data used in the appended papers is given in Table 3.4.

3.5 Focus groups

The focus group method of data collecting uses interviews with several people on a specific topic or issue, and is primarily an alternative to both individual interviews and surveys such as questionnaires. The focus group consists of several participants and one moderator, or facilitator. Audio or video recording equipment is generally used for data collection.

According to Patton (1990), it must be remembered that the focus group is an interview situation and not a discussion group, a problem-solving group, or a decision-making group. The focus group method is characterized by the following (Bryman, 2004):

- there is an emphasis in the questioning on a specific and fairly tightly-defined topic, and;
- the focus in the discussion is on interaction within the group and the joint construction of meaning.

Focus groups are considered to be a more effective tool than individual interviews; they tend to produce a large amount of data in a short period of

Table 3.4: Overview of the empirical material used in the studies presented in the appended papers

Appended paper	**A**
Type of study	Investigative
Characteristics	Theoretical analysis with some empirical data
Empirical material	Statistics, published texts
Data collection method	Surveys, Literature searches
Appended paper	**B**
Type of study	Investigative
Characteristics	Theoretical analysis with some empirical data
Empirical material	Published texts
Data collection method	Literature searches
Appended paper	**C**
Type of study	Descriptive
Characteristics	Theoretical analysis based on empirical data
Empirical material	Published texts
Data collection method	Literature searches
Appended paper	**D**
Type of study	Exploratory
Characteristics	Case study
Empirical material	Written and recorded material
Data collection method	Focus groups, interviews
Appended paper	**E**
Type of study	Descriptive
Characteristics	Case study based on ethnographic approach
Empirical material	Written and recorded material
Data collection method	Focus groups, interviews, artifact collection, audio and video recording
Appended paper	**F**
Type of study	Descriptive
Characteristics	Theoretical analysis based on empirical data
Empirical material	Published texts
Data collection method	Literature searches

Appended paper	**G**
Type of study	Exploratory
Characteristics	Case study based on action research
Empirical material	Written and recorded material
Data collection method	Observations, focus groups
Appended paper	**H**
Type of study	Descriptive
Characteristics	Case study based on action research
Empirical material	Written and recorded material
Data collection method	Observations, focus groups, interviews, audio and video recording
Appended paper	**I**
Type of study	Descriptive and Exploratory
Characteristics	Case study with action research elements
Empirical material	Statistical data, observations
Data collection method	Surveys, focus groups, interviews

time (Morgan, 1988). Morgan (1988) and Krueger (1988) have established that focus groups are useful primarily for the following tasks:

- orientation to a particular field of focus;
- the development of themes, topic, and schedules for subsequent interviews and/or questionnaires;
- the generation of hypotheses that derive from the insights and data from the group;
- the generation and evaluation of data from different sub-groups of a population;
- the gathering of feedback from previous studies.

Use of focus groups in the appended papers

Focus groups are used in five of the appended papers: D, E, G, H, and I (see Table 3.4). In each case the focus group consisted of one moderator/facilitator and between four and twelve participants, all students at either KTH or Stanford University. Each focus group session lasted between 30 minutes and two hours. Most sessions were recorded on video, but in some cases only audio was recorded, and in a few exceptional cases data was provided only by the notes of the facilitator. Each paper uses data from at least one and at most five focus groups.

The topics focused on were such things as interaction between the two distributed student teams in the studies of international collaboration, use of the laboratory equipment, and interaction between the students using individual laboratory equipment in the studies of experimental learning.

All these focus group sessions were aimed at generating and evaluating data from interventions or for case studies. In the cases presented in paper D and E, focus groups were used on two occasions during the courses being studied, once to generate hypotheses from the insight of the student teams, and a second time to generate and evaluate data to test the hypotheses. In the case presented in papers H and I, focus groups were used to develop themes, topics, and schedules for subsequent questionnaires.

3.6 Interviews

Interviews can be classified into a number of different types, each type having a different purpose and different advantages and disadvantages. Usually the different types are mapped on a scale from informal, conversational types of interviews to closed, quantitative types (Kvale, 1996). An interview's flexibility of purpose varies according to its place on this scale and its degree of structure.

Patton (1980) outlines four types of interviews, ranging from least structured to most structured:

Informal conversational interview This is the least structured and most informal interview. The interviewer controls the conversation, but question topics and wording are produced by the natural flow of discussion rather than being predetermined. This type is especially advantageous in exploratory interviews and when emotionally-significant topics must be handled.

Interview guide approach The topics and issues are specified in advance, but in outline rather than detail. The order in which to address the topics is decided by the interviewer, but the questions are formulated and presented as they arise naturally in the course of the interview.

Standardized open-ended interviews The exact wording and sequence of questions are determined in advance. This type is useful when the results of the interview are to be compared with those of other interviews.

Closed quantitative interviews This is the most structured setting, and can be described as a kind of human questionnaire. Its main characteristic is that the respondents choose their answers from a list of predefined ones.

Use of interviews in the appended papers

Interviews have been used in four of the appended papers (see Table 3.4), papers D, E, H, and I. In the first two studies the interviews were conducted twice during each study, while in the last two studies interviews took place once, at the end of the respective experiments. In most cases the interviews were performed to verify observations and in one case (paper I) to verify questionnaires. In some cases, however, interviews were conducted as exploratory interviews with the purpose of seeking and developing a hypothesis rather than the collection of data.

In all cases the interviews followed one of the two least structured settings, being either informal conversational interviews or interview guide approaches, depending on their purpose. For example, informal quantitative interviews were conducted in the studies presented in paper D and E, the Mucca and the Company cases to facilitate exploration of the area of international collaboration in order to find patterns of communication within the team and between the distributed teams.

3.7 Use of questionnaires in the appended papers

Quantitative questionnaires were used on only one occasion, in paper I, to collect statistical data from an experiment. In the questionnaire, approximately 100 students answered questions related to a particular course and a particular experiment, providing data on such things as attendance at lectures, time spent on laboratory exercises and grades.

3.8 Research quality

Researchers as human instruments

In the studies described in the appended papers, a human instrument was used for empirical data collection. In each case this instrument was the author of this thesis (Grimheden). In some cases, in particular in the data collection of the studies presented in paper D and E (the Mucca and the Company cases), the co-author of paper E (Strömdahl) participated as well, mostly in focus group sessions and interviews.

Methodological considerations

In most cases the choice of methodology was subsequent to other considerations, mainly other roles, responsibilities, and resources. In the Mucca and Company cases the researcher had a researching role disconnected from other faculty responsibilities; in other words, he did not take any responsibility for the teaching of the course. The study of case Mucca, and the empirical data gathered in this case study, led to a number of questions which made the choice of the ethnographic approach in the second study, the Company case, easy since the first study highlighted a need for further investigation of certain aspects. The choice of an ethnographic approach in favor of, for example, another case study, was motivated by the intention to run an active form of research, not in the form of intervention, but instead with the purpose of creating acceptance for an active role of the researcher. The active role was a result of the Mucca case where it was found that a non-participatory researching role did produce some results but did not create enough opportunities for deeper understanding. Regarding the issue of resources, the researcher also had the opportunity to spend considerably more time in the second case (Company) than in the first (Mucca).

In the studies related to experimental learning the focus was narrower and the choice of methodology was more directed toward action research. Both studies were based on the idea of change, an action or intervention, further motivating this choice of method.

Regarding the choice of methodology for empirical data collection and the three primary tools used, these were chosen according to an idea of the results that were expected. In the cases of exploratory case studies and pilot studies, focus groups and informal qualitative interviews were held, while in the cases where the focus was more narrow, for example those related to experimental learning, guide-based interviews and questionnaires were chosen.

Research quality and methodological considerations

In all cases the measurements were influenced by the choice of methods. The case in which the researcher most likely had the greatest influence was that in which he had the most active participating role, that is, the ethnographic approach used in the study of the Company case. The results of this case, however, are of a kind that do not in any way represent deductive evidence of relations between action and results, but simply identify certain changes, for example, signs of enhanced interdisciplinary learning.

In the cases related to experimental learning the studies were based on an intervention in the form of action research, but the researcher had a completely different role. In these cases the researcher was not directly involved either in the teaching of the course or by active participation, but rather by indirect data gathering on certain occasions. In these cases the results are more quantitative than in the previous cases, comprising such things as changes in student grades. These results could be affected by the intervention, but it should be remembered that the intervention only represents one variable among many.

To summarize, methodological choices were motivated by the nature of the results expected from each particular case and study. The researcher had influence in all cases, but the results were analyzed accordingly, taking into account considerations of the participatory role of the researcher which, while enabling the gathering of certain empirical data, also created conditions on the applicability of the conclusions.

Chapter 4

Current trends in engineering education

University-level engineering education has been the focus of keen debate during the last two decades. This intense interest could be related to decreasing numbers of students applying for university programs in some countries, an increased number of new university programs, and an overall downturn in the appeal of engineering education to young people. A number of activities or trends with the underlying goal of attracting more students can be identified; the following examples are taken mainly from Swedish higher education.

- Tighter focus on specifics. Moves are being made from traditional engineering education, such as mechanical engineering and computer science, toward more specific programs that aim at a narrower industrial branch, for example courses in product development, innovation, and robotics (Grimheden et al., 2005; Grimheden and Andersson, 2004).
- Internationalization. Most European countries are well-progressed in terms of adapting engineering programs according to the Bologna process, and are developing and implementing internationally-accepted M.Sc. programs (Kansli MMT, 2003).
- Industrial relevance. Industry has begun to take a greater interest in education, and industrial representatives have expressed a need to change engineering education in order to provide engineers suitable for specific positions and with a high degree of complementary skills such as project management, teamwork, and communication (Josefsson, 2003; Wikström, 2004).

4.1 Reconceptualizing higher education

To cope with these changes, the role of the faculty needs to be reconceptualized and redefined. Some possible outcomes of this are as follows:

Faculty as mentor Teachers are no longer teachers in the classical sense. No individual has all the answers and no one person is in control of information flow, setting the boundaries of what the student should and should not know. The faculty members must act as mentors and coaches to support the individual learning processes. This is especially relevant in interdisciplinary activities such as product development where synergistic integration between different faculties is vital.

Faculty as resource creator Globalization means that students can — and do — take courses anywhere in the world. The amount of information available is enormous. An important role of the faculty is to create structure in this vast pool of information, to guide students to the available resources, and to enable appropriate methods of approaching the content. Such guidance could be considered to be more useful to students than the information itself.

Faculty as entrepreneur and program developer Faculty as mentor focuses on one individual student, and faculty as resource creator focuses on the classroom level. Equally important is the ability of faculties to create ties to industry, to develop new programs, and to provide structure for the increasing number of courses available worldwide (Chen et al., 2001).

Depth instead of width The interdisciplinary nature, thematic identity, and functional legitimacy of product development focused engineering requires undergraduate education to be concerned with depth rather than width. Projects must be relevant, and students must focus on gaining actual experience of the product development process rather than just theoretical knowledge of it (Grimheden and Hanson, 2003a).

Industrial relevance and enhanced motivation The integration of large-scale industrial projects into capstone courses in higher education has proved in many instances to be successful in increasing student motivation and in providing a link to industry during the final years of study; for example at Luleå, Sweden (Larsson, 2005), at KTH (Hagman et al., 2001; Grimheden and Hanson, 2003a), and at Stanford University (Leifer, 1997).

4.2 From teaching to learning

A recent and significant paradigm shift in higher education was first identified by Barr and Tagg (1995) in a well-cited article that prompted considerable discussion around the world. The former traditional way of teaching, the instruction paradigm, is in the process of being replaced by a new approach, the learning paradigm.

Characteristics of the learning paradigm include a move from formal legitimacy toward functional legitimacy and a shift in focus from formal assessment methods, course content, and marks or grades to newer methods grounded in increased feedback, individual support, and coaching.

The rise of the learning paradigm has been motivated by such things as the rising cost of academic education, aspiration for freedom from the rigid and complex structures that constrain higher education, and, primarily, by teachers' desire to improve student learning by providing increased motivation and enhanced flexibility. In the case of design engineering a parallel can be made to the notion of regarding the subject as having a functional legitimacy. According to Barr and Tagg (1995) a move toward the learning paradigm will not only increase the "quality of learning for students" but also enhance "intellectual skills such as writing and problem solving and social skills such as effective team participation" — functional skills, not formal knowledge.

4.3 From engineering design to design thinking

The evolution of the concept of engineering design has some similarities with the changes that occurred in medical teaching during the 1960s. As described in section 2.4, problem based learning developed there as a reaction to the change in legitimacy from formal to functional.

The notion of engineering design captures a move from more traditional academic subjects such as mechanical engineering toward more applied subjects where knowledge in, for example, mechanical engineering is used and applied in the creation of products and processes. In one sense this can be described as a change in focus from analysis to synthesis — engineers are not taught to analyze existing products but to create new products. These ideas are summarized by Dym et al. (2005) into the following definition:

> "Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints."

It is a matter of constant debate whether creativity — an essential part of design and synthesis — can be taught at all. However, a review by Torrance (1987) of 142 studies of attempts to teach children to be creative shows that creativity can indeed be taught if the educational process focuses on cognitive and personality factors, promotes good motivation, and permits active student involvement. It is fairly clear that problem based learning, product based learning, and collaborative learning all correlate with these requirements for creativity teaching.

Dym et al. (2005) further set out to highlight the skills associated with engineering design, or 'good designers', stating that a good designer is characterized by the ability to:

- tolerate the ambiguity that stems from viewing design as inquiry or as an iterative loop of divergent-convergent thinking;
- maintain sight of the big picture by utilizing systems thinking and systems design;
- handle uncertainty;

- make decisions;
- think as part of a team in a social process; and
- think and communicate in the different languages of design.

In summary, it can be established that the move from traditional engineering and engineering design to design thinking; from analysis to synthesis, and toward creativity teaching, has much in common with the approaches of project based learning and product based learning as well as with collaborative learning in general.

4.4 A new requirement for educational skills

Historically, no educational training whatsoever has been required from teaching staff at universities; many readers will be familiar with the experience of both professionally-delivered university courses and the opposite. However, this situation is changing. Recent increases in requirements for both educational training and teaching skills are here illustrated by some examples from the Swedish Higher Education Act and Ordinance, which together regulate all higher education in Sweden.

> "Only a person who has shown academic and teaching skills may be appointed professor" (The Higher Education Act, 3rd Chapter, §2, Law 1997:797)

These requirements are stated more specifically in the Higher Education Ordinance:

> "A person is qualified to be employed as senior lecturer if the person:
>
> 1. holds a doctorate or corresponding academic qualifications;
> 2. holds a degree in education or has acquired corresponding qualifications, and;
> 3. has demonstrated teaching skills."
>
> (The Higher Education Ordinance, 4th Chapter, §7, Ordinance 1998:1003)

Finally, the Ordinance directs the extent to which educational skills are to be assessed by the employing university:

> "As much attention shall be given to the assessment of teaching skills as to the assessment of other circumstances forming the basis for qualification" (The Higher Education Ordinance, 4th Chapter, §7, Ordinance 1998:1003)

To summarize: according to the current Swedish regulations, the pedagogical requirements of teaching staff at universities are high, even to the extent where the hiring committees are directed to pay as much attention to assessing teaching skills as scientific skills. This is a very strong sign of significant change in higher engineering education.

4.5 International trends in mechatronics education

To conclude this survey of the ongoing changes in engineering education, a brief overview of some international initiatives is now provided.

The CDIO initiative

The CDIO initiative was established by KTH, MIT, and a number of other Swedish universities to move engineering education further away from a formal legitimacy toward a functional. Its purpose is to create a curriculum for training students to Conceive, Design, Implement, and Operate a system (Crawley, 2002).

The CDIO initiative comprises the CDIO standards and the CDIO syllabus. The standards describe the guiding principles of CDIO educational programs, and can also be used by the hiring industries as definitions of the student knowledge and skills delivered by such programs. The syllabus consists of a detailed and well-specified list of the learning objectives, structure, and content of CDIO courses (Bankel et al., 2005).

One fundamental aspect of the CDIO initiative is that each learning objective, skill, or element of knowledge forms a part of at least three courses, being introduced in one course, practiced in another, and finally used in a third. No distinction is made between scientific knowledge and complementary skills — any course can include either or both, for example, knowledge of mechanics could be addressed in the same course as teamwork skills. These three steps ensure that knowledge and skill are not forgotten through neglect but rather reinforced by repeated exposure (Bankel et al., 2003).

The CDIO syllabus has been implemented in full at some universities, for example MIT (Crawley, 2002), while other institutions have adopted the basic ideas of the CDIO initiative without accommodating the entire CDIO program. One example of this is found at KTH, in the subject of mechatronics, where the CDIO idea is implemented in the fourth and final year of the specialization as a completely problem and project based course. In this course, a team of six to fifteen students are given a task, typically in terms of an industrial development project involving concept evaluation and prototype development, where a corporate sponsor provides the problem, motivation, relevance, and funding. The student team spends more than 50% of their time during the nine months of the course on a project that is organized in the four C-D-I-O phases. Complementary skills such as teamwork skills, project management, economy, and language skills are interwoven into the project as each student receives two responsibilities, one related to the product and one related to the process. Student responsibilities are cycled in each phase, and by the end of the course each student will have practiced their skills in embedded systems technology as well as such areas as team management and teamwork.

The REM network

The REM network was founded in Bochum, Germany in 1999 with the goal of fostering Research and Education in Mechatronics. Although most current members are European, it is a worldwide society.

In contrast to the CDIO initiative, the aim of the REM society is to facilitate meetings between mechatronics educators and practitioners, rather than to create common directives and programs. It has produced a few grassroots attempts to create a common curriculum, but nothing concrete has yet been established. Instead, the curricula of the various universities are published and discussed, experimental laboratory equipment is shared, and initiatives are taken toward summer schools for doctoral students and worldwide student competitions (REM Network, 2005).

This association of researchers and educators is by no means unique, but the existence of the REM society does highlight a growing desire for international collaboration, educational exchange, and a common curriculum for mechatronics education.

The ARTIST initiative

The ARTIST initiative is similar to the CDIO initiative in that one of its goals is to establish a common curriculum and foster consistent educational standards. Like the CDIO syllabus, the ARTIST initiative specifies knowledge and skill requirements in detail; but it then diverges from the CDIO program in that it focuses mainly on scientific areas rather than also covering complementary skills (Caspi, 2003).

ARTIST has its basis in computer science rather than mechanical engineering, and aims to promote excellence in embedded systems design. However, in a sense embedded systems can be seen as a subset of mechatronics, and there is clear overlap in certain aspects of the two subjects due to their thematic identity.

One interesting and relevant trend is the ambition of the ARTIST network to touch on academic areas outside the sphere of computer science, and to view the subject of embedded systems design as a multidisciplinary subject that requires a large number of skills from other fields such as control theory and electrical engineering. This, and in particular the need for appropriate education in this field, has been manifested by the establishing of a first series of workshops for education in embedded systems design, organized by the Association for Computing Machinery and its special interest group on embedded systems (Caspi and Jackson, 2005).

4.6 Mechatronics in the perspective of engineering education in change

The preceding discussion of changes occurring in engineering education can be summarized in the following points:

Modernization Development and modernization in higher education points toward the need to move from teaching to learning, from theory to application, and from action to interaction.

Internationalization Internationalization and globalization have created a need to find common curricula and common ground between universities teaching similar subjects. Several international networks and programs are attempting to bridge this gap.

Industrial relevance The need for industrial relevance is imminent; the requirement for functional legitimacy is on the increase, and hiring companies are requiring functional skills more than ever before.

Legitimacy Functional legitimacy requires a move from more traditional analytical skills toward more creative aspects such as design and synthesis, particularly in the areas of engineering design and product development.

Trends Contemporary educational initiatives such as the CDIO initiative emphasize the need for and the possibilities inherent in a transformation of traditional engineering educational programs into design-related programs adapted to the industrial need for engineers capable of designing products.

In the light of the discussion above, the subject of mechatronics should now be put in focus.

Chapter 5

The subject of mechatronics

The first question to answer is *What is special about mechatronics?* An attempt at an answer is presented in the first appended paper, “What is Mechatronics — Proposing a Didactical Approach to Mechatronics” (Grimheden and Hanson, 2001) and followed up in the second paper, “What is Embedded Systems and how should it be taught — Results from a didactical analysis” (Grimheden and Törngren, 2005). The technique used in the analysis is that of the previously-described method of subject didactics, and is based on studies of the subject of mechatronics as taught at KTH and at several other universities. In this analysis the identity of mechatronics is identified as thematic rather than disciplinary, and its legitimacy is identified as functional rather than formal.

5.1 Is mechatronics really different from traditional subjects?

Many authors have attempted to answer the question above since mechatronics was first established as an academic subject. As mentioned earlier, Harashima et al. (1996) were among the first to pinpoint its unique identity by identifying the concept of synergy, or synergistic integration, as the foundation of mechatronics.

In an early article on the subject Hanson (1994) describes the evolution of the definitions of mechatronics, starting in the 1970s:

> “microcomputers in mechanical systems” (KTH, Sweden, 1970s)
>
> “application of microelectronics in mechanical engineering” (Japan, 1970s)
>
> “computer controlled mechanics”, “microcontrollers in embedded products”, “microcomputer systems design” (KTH, Sweden, 1980s)

Other contemporary authors attempted to introduce other definitions, among them being the following one presented by Auslander in 1996 and published along with the Harashima definition in the very first issue of IEEE/ASME Transactions on Mechatronics (Auslander, 1996):

> “the application of complex decision making to the operation of physical systems”

Starting in the 21st century, definitions focusing more on the synergistic aspects of the subject became predominant, several of which basically repeated the Japanese definition from 1996. Examples of this can be found for example in a special issue of IEEE Robotics and Automation Magazine dedicated to mechatronics education:

> “. . . a blend of mechanics and electronics, mechatronics has come to mean the synergistic use of precision engineering, control theory, computer science, and sensor/actuator technology design to design improved products and processes.” (Erkmen et al., 2001).

In the same issue, Craig answers the question posed in the title of this section, and describes what he considers is “new in mechatronics education” (Craig, 2001):

> “All mechanical engineers must become mechatronic engineers, regardless of their concentration. Mechanical engineering professors teaching design must teach an integrated approach to design — mechanical, electronic, controls and computers — and so must become proficient in these areas. (...) Industry wants and needs these skills in our mechanical engineering graduates, and professors must meet this challenge head on.”

5.2 The identity of mechatronics

In a didactical analysis, the identity of a subject can be described in terms of the two extremes of disciplinary identity and thematic identity. The question of identity is defined as ‘what distinguishes this particular field of knowledge?’ Most traditional subjects such as mathematics, chemistry, and physics are viewed as disciplinary, meaning that there exists a strong consensus in the surrounding society regarding the content of the subject and its classification and organization. Often, knowledge is organized and developed systematically, and once created is easily classified into the existing structures.

It is clear from the examples provided in the previous section that there is no strong consensus over the identity of the subject of mechatronics. Its definition has varied with time and location ever since its introduction.

One possible way of classifying the identity of such a subject is to find a common denominator among its varied definitions. Two concepts stand out strongly here: the idea of synergy, and the need for complementary skills. Thus mechatronics quite clearly has a thematic identity; it is described solely in terms of themes, and there is no universally-accepted definition of either the subject, or its preferred curriculum, or its place in academia.

5.3 The legitimacy of mechatronics

The question of legitimacy is defined as the relationship between the outcome of the educational efforts undertaken by the university and the actual demands that are put upon the students' abilities by society or industry at the end of their education. This relationship can take the form of either formal legitimacy or functional legitimacy.

One example of formal legitimacy in a mechatronics engineering context would be the requirement that engineers have a certain number of credits in a certain subject, for example, ten credits in control theory, where credits are awarded for reading certain textbooks or performing certain experiments. A functional legitimacy would instead require a certain level of skill in the application of the subject; in the control theory example, for instance, that the engineer should be able to design a PID-regulator, to discretize it, and to translate to C code for a microcontroller with certain specifications. Note though that the difference between a formal legitimacy and a functional legitimacy is not related to the depth of understanding or knowledge, but rather to how this depth of knowledge or understanding is specified or measured.

When discussing legitimacy, it is important to note its strong dependence on context. For example, a student specializing in theoretical mathematics might well fulfill functional needs related to solving certain analytical problems in industry; a competence that might well be regarded as formal in other contexts. In addition, a given educational method is not necessarily restricted to the production of only formal knowledge or only functional skills, even though certain educational methods are more strongly associated with either one or the other (Grimheden and Hanson, 2001).

The connection between knowledge and skill also makes it difficult to properly value a student's knowledge and skills. A hiring industry might for example search for a person with a specific set of skills to meet a particular need at the company, but a few years later that need may no longer exist. At this point formal knowledge could be more useful than functional skills: a high level of formal knowledge can facilitate the development of new functional skills. A hiring industry that makes functional rather than formal demands runs the risk of exaggerating the need for specific skills over general knowledge.

The subject of mechatronics is best characterized by a functional legitimacy, one primarily related to its thematic identity. Its basis in the concepts of synergy and product development requires that proficiency be measured by the ability to create synergy by using knowledge and skills in several subjects and the ability to develop products in which this synergy is manifested.

5.4 The selection of mechatronics

The questions of selection and communication address the issues of how a subject should be taught and what aspects of it should be studied. The two extremes of selection are horizontal representation and vertical exemplification. Horizontal representation implies a broad representation of the entire subject, meaning that education should include samples of every aspect of the subject. On the other hand, in a vertical exemplification one or more particular areas within the subject are studied in depth.

An illustration of the question of selection could be an example of how to plan for an education in mechanical engineering. A large number of possible approaches exist, for example when comparing different models for product development. A course in design methodology could on one extreme focus on one particular design methodology in depth, or in the opposite on covering a large number of available design methodologies. To focus on one methodology in depth would point toward a vertical exemplification and the attempt to cover all methodologies would point toward a horizontal representation.

As with the previous questions it is not a matter of choosing one of two extremes, but rather of finding an appropriate balance between the two. Most engineering courses use both horizontal representation and vertical exemplification; usually the first years are dedicated to representation and the later years to exemplification.

There is a deep connection between the question of selection and the question of identity. If a subject has a thematic identity then a horizontal representation is difficult to achieve, since only if the identity is disciplinary does there exist consensus over content, definition, and structure. For example, it is not difficult to find an appropriately representative textbook in mechanical engineering, and indeed introductory courses for engineering students do tend to be very similar, but for a subject such as mechatronics this is much more difficult since every textbook emphasizes different aspects. It is equally difficult to establish universal agreement over curricula and courses, since every teaching team reflects the local interpretation of the subject.

A thematic identity therefore implies an exemplifying selection. A similar connection can be made between the question of legitimacy and the question of selection.

The functional legitimacy implies a focus on skills, abilities, and applied knowledge rather than more abstract knowledge. The applied knowledge is related to the theme, the examples, which in the case of mechatronics are illustrated by keywords such as synergy, product development and complementary skills. If compared to the earlier example with design methodologies: an education in mechatronics, where a vertical exemplification is chosen, a course in design methodology could be focused on learning and using one design methodology. Since the legitimacy of the course and education is related to the abilities to develop products the legitimacy of the course in design methodology could be reached if the design methodology was seen as a tool to facilitate product development.

This is however a controversial standpoint. Several courses in design methodology aims at giving a broad overview of the existing design methodologies; their pros and cons etc. This is definitely a valuable aim, but if the connection is made between the legitimacy and the selection, the opposite could be argued. If the university is educating students into mechatronic product developers the approach (or selection) should be different, in that case it is irrelevant which and how many design methodologies the student knows, what's relevant is the students' abilities to develop mechatronic products, by using several tools, for example design methodologies.

An immediate consequence of the above reasoning is the form of the education; if it is abilities and skills in using, for example, design methodologies that are in focus, how could the education be organized to facilitate this?

To conclude — the selection of mechatronics would benefit from an exemplifying selection, primarily due to the reason that the legitimacy is defined as functional and the identity as thematic.

5.5 The communication of mechatronics

The question of communication can also be viewed in the light of two extremes — active communication and interactive communication. Active communication can be seen as a feed-forward open-loop control system where education is based on a prior understanding of how the material should be communicated, or on other models of student learning behavior. Interactive communication is more like a closed-loop control system where the actions performed by the educator are based on the current status and knowledge levels of the individual student or student team.

As described earlier, there is a direct connection between the identity and the selection of a subject — a thematic identity requires a vertical, exemplifying selection. Similarly, there is a connection from a subject's legitimacy through its selection to its communication. The functional skills required by the hiring industry are developed by emphasizing project work, team work, cooperation with industry, and so on, which in the end is facilitated by all education being based on an interactive communication, preferably with a strong focus on project based work.

How to teach mechatronics in accordance with these results

The teaching of mechatronics with a vertical exemplification and an interactive communication requires that emphasis be placed on the application and synergistic use of previously-acquired knowledge and skills in subjects such as mechanical engineering and electrical engineering. Knowledge alone is not sufficient; it is also necessary to teach the skill of using one's knowledge, for example, to develop products, and a truly holistic viewpoint requires not only knowledge of the entire chain of subjects and the different product development stages also actual experience of all aspects of product development.

The preceding conclusions from the didactical analysis of the subject of mechatronics are illustrated in Figure 5.1.

5.6 The evolution of the subject of mechatronics

The third appended paper proposes a model for the evolution of the subject of mechatronics. This model divides the evolution into six stages, which are presented in Figure 5.2. Some evidence for this model can be observed when

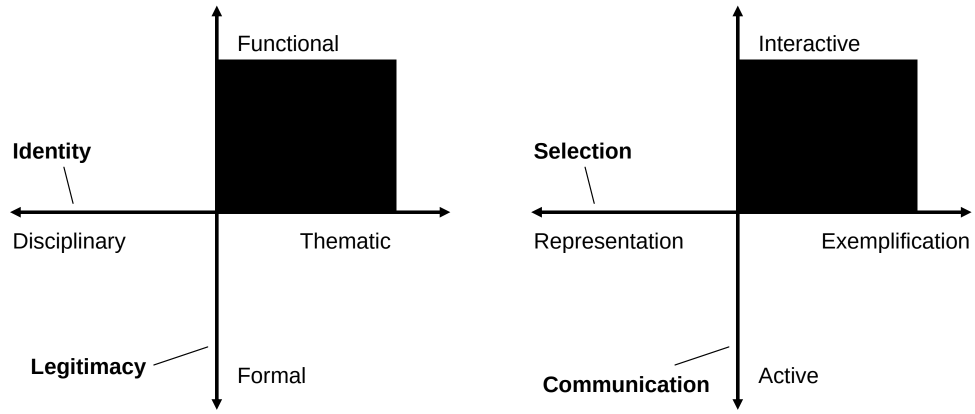

Figure 5.1: The four didactical questions applied to the subject of mechatronics

studying how newer academic subjects have emerged based on certain needs and on existing disciplines. This is for example the case for the subjects of strength of materials, solid mechanics, and automatic control. To illustrate this model, consider the subject of automatic control where needs and thus a theme emerged in the early 20th century; in this case the originating disciplines were electrical engineering and physics. Automatic control has since developed into a well established academic subject; thus the original theme has been further developed and a research discipline has emerged (Abramovitch and Franklin, 2004).

The evolution of an academic subject is divided into six stages. In the first stage (1) no interaction between the original disciplines exists. The second stage (2) represents a multi-disciplinary situation in which students combine courses from different disciplines to broaden their knowledge, and a common theme has been identified. In the third stage (3) efforts are made to organize and offer cross-disciplinary courses, for example consciously giving courses in embedded systems by teaching electrical engineering, automatic control, and computer science to mechanical engineering students. At this stage, it is usually one discipline that takes the initiative for the cross-disciplinary courses. In the fourth stage (4) new curricula are created, and the original disciplinary identities begin to diminish in favor of the evolving thematic identity.

The last two stages are characterized by a change in organization (5) where the faculty begins to rely less on competencies in the various traditional areas but instead on competence in the newly-evolved subject, for example by hiring staff with a degree in mechatronics rather than in one or more of the traditional subjects. The final stage (6) connects back to the first step; there are now opportunities for evolution of yet more new academic subjects. For example, when — and if — the discipline of mechatronics becomes fully established, it would be fruitful to discuss how this new discipline (however thematic) relates to neighboring subjects (either disciplinary or thematic). An example of this final stage can be seen in the subject of automatic control, where themes relating

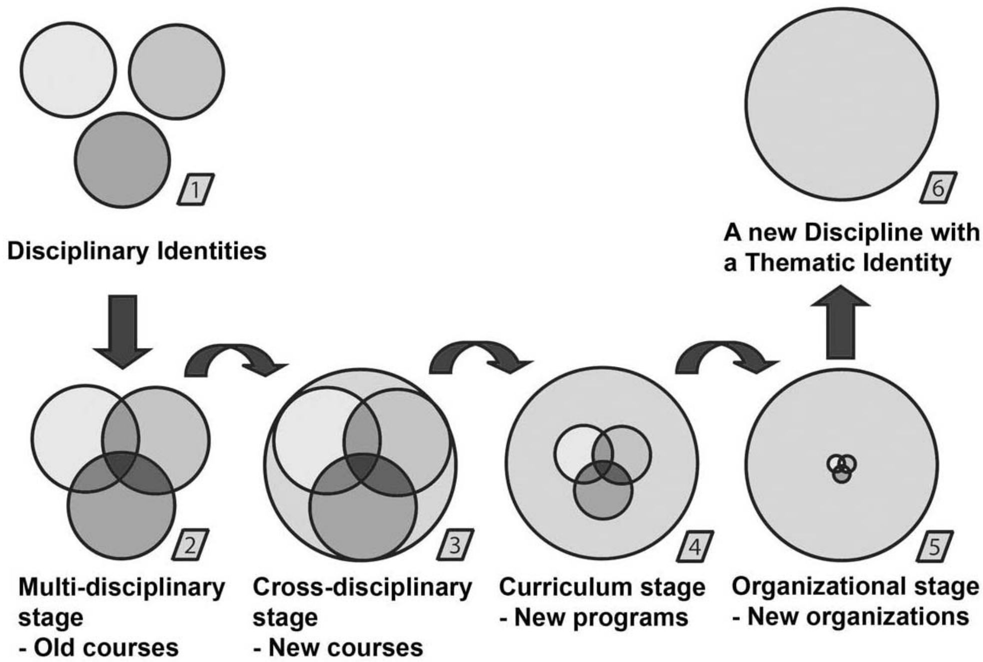

Figure 5.2: The evolution of the subject of mechatronics

to several other disciplines have been emerging, such as the ARTIST2 Network of Excellence (ARTIST2, 2005) which has defined a cluster with the aim of developing the connections between automatic control and computer science.

The increasing complexity of mechatronics applications will require stronger interaction between more or less isolated academic disciplines in order to stimulate the identification and evolution of new themes. As indicated by the framework laid out in Figure 5.2, the required multidisciplinary interactions can either be achieved by broadening the scope of one discipline, corresponding to an evolution to stages 3 or 4, or by developing entirely new disciplines. For example, there is a clear need to educate specialists in the fields of integrating software (computer science, software engineering), hardware (electrical engineering), and controllers (automatic control) in their real-time implementations (computer science, software engineering, electrical engineering).

In the third paper (Grimheden and Hanson, 2005) results are presented from a survey of a number of north European universities teaching mechatronics, and the respective universities are mapped to the different stages of the model, or rather, examples are chosen from a number of universities to illustrate the model. Note that this model also appears in the second paper (Grimheden and Törngren, 2005), where it is applied to the subject of embedded systems.

Chapter 6

International collaboration in mechatronics education

The notion of international collaboration is motivated by the definition of mechatronics as having a thematic identity and a functional legitimacy. Functional legitimacy implies that education should lead to functional skills within product development, and since basically the entire industry dealing with mechatronics product development has an international market, and in the case of the major international companies, also deals with globally distributed work, international collaboration in mechatronics education is likely to be useful in preparation for future work. As shown in appended papers D and E, international collaboration can also promote a number of intra-disciplinary skills as well as complementary skills such as communication skills. Also, enhanced student motivation is a related effect to the international collaboration (Grimheden and Hanson, 2003a; Grimheden and Strömdahl, 2004; Collis et al., 1997; Hamada and Scott, 2000; Leifer, 1997; Maxwell et al., 2000; Wilczynski and Jennings, 2003).

6.1 Why international? Why collaboration?

The advantage of studying abroad is primarily that by working with students from different universities, cultures, and disciplines, students can encounter different ways of approaching problems and can access a broader variety of knowledge and skills within one discipline as well as practicing their language skills and widening their horizons.

When comparing national collaboration with international collaboration the advantages with the international settings are also obvious if related to the goals above; experience from working with students and faculty from various cultures and countries, the practice of language skills etc.

These are commendable aims, but the question remains: is it possible to reach the same goals without traveling? The fifth appended paper, paper E, tries to answer this question.

Another answer to the question of ‘why international collaboration’ is quite simply ‘because we can’. With the advent of modern communicational technologies it is relatively easy to connect student teams globally and to provide platforms and equipment for sharing information and labor. It is difficult to overestimate the importance of these experiences and skills for a future career in a multinational company.

The following examples of the situation within typical Swedish companies may help to illustrate the environment that a mechatronics engineer will need to fit in to:

- many of the companies hiring mechatronics engineers from KTH are large, multinational companies;
- most Swedish mechatronics companies have a global market;
- local research and development teams constantly collaborate with other teams within their multinational company.

  (Grimheden and Strömdahl, 2004; Horvath et al., 2001; Maxwell et al., 2000; Josefsson, 2003)

These observations, together with the previously presented didactical analysis (Grimheden and Hanson, 2001; Grimheden and Törngren, 2005), lead to the following requirements for the mechatronics engineer:

- the ability to work with engineers and experts from traditional engineering areas, for example, mechanical engineering and electrical engineering;
- the ability to follow, and make use of, technical progress in the other disciplinary fields;
- the ability to lead multidisciplinary teams.

  (Grimheden and Hanson, 2003a; Wikander et al., 2001)

It therefore follows that the industry should require international competence of the mechatronics engineer, meaning:

- experience of working in an international team;
- experience of working with colleagues and competitors in, and from, various parts of the world;
- experience of working with colleagues from different educational backgrounds and from other educational disciplines.

  (Grimheden and Strömdahl, 2004; Wagner and Steinführer, 2001; Knoll and Jarvenpaa, 1995; Hamada and Scott, 2000)

6.2 Studying abroad

There are several references in the literature to the effect that studying abroad has on learning. Martin (1994) defines the *international sojourner* as the student studying abroad and gaining intercultural experience. Martin (1994) and

Kim (1988) have investigated the mechanisms underlying the adaptation of the sojourner to the foreign country, and found that one important aspect is communication between the sojourner and his/her hosts. Kim (1988) concludes that the individual, the sojourner, is likely to gain a “broader perspective” from the “increased cognitive complexity” which results from the “adversarial nature of the cross-cultural adaptation process”. Further, the main experience gained when studying abroad is rather distant from the actual courses taken, which, according to Harrison and Hopkins (1967), implies a greater focus on integrative education, meaning that complementary skills, for example, gained from experiences from being abroad, should be considered as an important part of the educational aims (Newell, 2001).

In contrast to the international sojourner, the main question posed as a hypothesis for papers D and E is:

> Is it possible to reach the goals related to studying abroad, but without traveling?

6.3 Education as preparation for future work in a global market

As explained above, functional legitimacy implies the need for global competence to be incorporated into an education in mechatronics. One way of doing this is to expand a capstone course to include international collaboration (Grimheden and Hanson, 2003a) as either collaboration with a foreign corporate sponsor or collaboration with one or more international student teams.

Among other things, international collaboration in capstone courses has been found to promote:

- Improved disciplinary learning and other skills. International collaboration provides access to more resources and fosters new and different perspectives to problems. Collaboration also promotes general skills such as teamwork, team management and presentation techniques.
- Awareness of cultural differences and different educational systems, an important competence for a future career in a global company.
- Enhanced motivation. International collaboration is often perceived by students as an interesting challenge in itself.

Thus, the advantages of international collaboration can be seen to include functional legitimacy related both to the subject of embedded systems and to the general skills needed to work effectively in a global company.

6.4 Modes of international collaboration

Paper F presents five different modes of international collaboration, each based on a set of constraints. The following definitions are used:

Students Students are either considered as individual students or as members of teams. A student team is defined as a group of students physically located at one university; no one team is divided between different universities.

Student teams and projects A student team is assigned a project. The same project can be assigned to several different teams.

Corporate sponsor The project is usually provided by a corporate sponsor, which normally assigns one or more corporate liaisons to act as contacts for the students. These liaisons act both as founders of the project and as customers.

Faculty The faculty provides resources in terms of facilities, equipment, and professional expertise.

Coaches The coaches are the project facilitators who guide the student teams throughout the product development process. Coaches can be specialists in, for example, design, collaboration, methodology, or teamwork. They are not normally involved in grading the students.

Under this framework, there are a finite number of possible modes for international collaboration; the international aspect can come from one or more of the individual students, the student teams, the coaches, or the corporate sponsors.

Individual students studying abroad

Individuals who wish to study in other countries usually either spend one or two semesters at a foreign university, or execute their masters thesis project abroad. They often receive extensive insight into other educational systems and cultures (Martin, 1994; Kim, 1988). This process is facilitated by exchange programs, but it can be difficult to find compatible curricula at other universities. Moreover, organizing and supervising a masters thesis project for a foreign student creates a large workload for a faculty, and external funding is usually required.

Project competitions

Examples of international student competitions include the Micromouse competition (Micromouse competition, 2004) and the Formula Student competition (Formula student, 2004). One of the major benefits for the student teams involved is the insight that these competitions provide into different educational systems and cultures. However, there is no focus on collaboration; and indeed communication between student teams, at least prior to the actual race, is almost nonexistent due to the competition factor.

Project based courses with a foreign corporate sponsor

In this mode, the corporate sponsor is located in a different country from the faculty and the student team. Since there are usually no other students involved, this setting obviously cannot increase understanding of foreign educational systems. It can provide a valuable context for the experience of working in industry-like conditions, and offer insight into foreign work cultures But, at least in the cases studied, students generally do not gain a particularly large amount of experience of working in a global team or with colleagues of different backgrounds, since the sponsor can provide only limited resources for collaboration (Grimheden and Hanson, 2002),

Project based courses with international partners

The most commonly-studied scenario is the one in which two distributed student teams share one corporate sponsor (Grimheden and Hanson, 2003a; Grimheden and Strömdahl, 2004). One of its advantages is that the teams can and must work together in order to complete the project and provide a satisfactory solution to their common sponsor. However, the physical location of the corporate sponsor can cause inequality between the two universities involved; if one of the teams has easier access to the sponsor it can end up acting as a filter between the sponsor and the more physically-distant team.

Team collaboration in an equally distributed setting

This mode represents an attempt to cope with the potential bias of a corporate sponsor toward the student team which is physically closest. In its ideal implementation, each university provides an equal contribution of corporate sponsors, student teams, and faculty members; and students are equally divided among different projects (Larsson, 2005). Its disadvantages are its relatively high complexity and the increased need for coordination between the faculties.

Summary of modes of international collaboration

International collaboration has two main categories of benefits. The first is that of providing experience of working in a global setting in order to prepare students for future work in a multinational company. For this category, the first and the third modes are the most beneficial: either individual students performing their thesis projects abroad or project based courses with foreign corporate sponsors.

The second category is more directly related to the special identity of the subject of mechatronics. As discussed earlier, mechatronics benefits from being taught in an international setting, and a mechatronics engineer needs more cross-disciplinary communication skill than does a traditional engineer. Thus the fourth and fifth modes are likely to be extremely useful for mechatronics education since their primary benefit is to promote transnational collaboration between students. The experience of working with global, diverse teams is valuable preparation for a future career in a global market, and differences between universities, students, and cultures are seen not as disadvantages but as a learning tool.

6.5 International collaboration in mechatronics education

Papers D, E, and F present two studies of international collaboration in mechatronics education. The first two papers cover experiments performed mainly at two nodes — KTH and Stanford University — in settings of the kind previously described as project based courses with international partners. The third paper, paper F, presents a summary of all internationally collaborative projects undertaken within the framework of this thesis project.

International collaboration is also touched on in papers G and H, which describe the use of a team of students at KTH working with a corporate sponsor based in Boston, USA — in other words, a project based course with a foreign corporate sponsor — to study experimental learning in mechatronics.

The international setting for the experiments described in papers D and E is detailed in Figure 6.1. The primary analysis performed on the collaborative project was an attempt to describe and analyze the communication that took place within it. Figure 6.1 illustrates the intensity of communication between each of the five nodes — the two faculties, the two student teams, and the corporate sponsor. The following conclusions can be drawn:

- Both faculties had intense communication with their respective student teams.

- Communication between the two student teams was intense.

- Communication with the corporate sponsor was more intense in the KTH case than in the Stanford case. The main reason for this is that the corporate sponsor in both studies was located in Sweden; in the first case approximately 20 kilometers from Stockholm, and in the second case inside Stockholm. This disparity in communication intensity occurred both with the student teams and with the faculties.

- Cross-communication between local faculty and distant student team was more intense between the KTH faculty and the Stanford student team than between the Stanford faculty and the KTH student team. This was mainly due to both differences in educational traditions and to the physical location of the corporate sponsor; the KTH faculty felt a stronger responsibility to satisfy the corporate sponsor and thus had greater incentive to motivate and include the Stanford student team in this process.

- Communication between the two faculties was considerably less intense than communication between the student teams. One disadvantage of this was that information provided by one faculty to the other sometimes traveled via the student teams; the KTH student team informed the KTH faculty of something related to the Stanford faculty, or vice versa. In some cases this made the students lose confidence in the faculties' management capabilities.

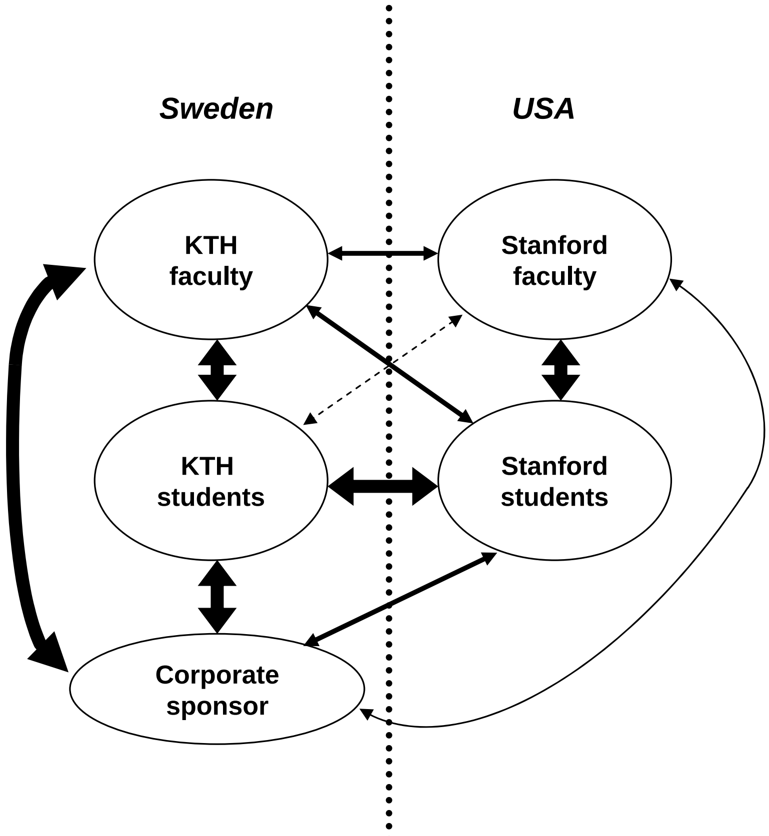

Figure 6.1: International setting for experiments performed in paper D and E together with results from studies of communication between the nodes. The thickness of the arrows represents intensity in communication. Dashed arrow represents hardly no communication at all. This is a slightly modified version of a figure presented in papers D and E, for clarification.

6.6 Results from international collaboration in mechatronics education

The results from the international collaborative experiments presented in papers D and E can be divided into three categories, which are summarized below.

Improved disciplinary learning and other skills

Signs of both increased interdisciplinary learning and improved complementary skills were found. The student teams learned from each other and made use of their disparate backgrounds in an efficient way; each individual was seen as a resource for information, knowledge, and lessons learned from previous experience. The distance in space and time required the students to use technology for distance communication, for example email, videoconferencing, and the telephone; and signs were found of increased skills in both the use of these tools and in communicating with limited modalities, for example describing technical details and phenomena with little or no visual communication.

Increased awareness of cultural differences and different educational systems

Each student team gained insight into the other's academic culture, student culture, and university culture. The student teams met once in each experiment; in both cases the Stanford student team visited Sweden and KTH.

Enhanced motivation

In both experiments the students expressed an increased motivation for learning, for taking the course and for committing themselves to the project. Every one of the KTH students stated in interviews that they preferred the international project to local projects.

Chapter 7

Experimental learning in mechatronics

The experimental approach to education in mechatronics, like the use of international collaboration, is inspired by the didactical analysis of the subject. Functional legitimacy suggests a focus on functional skills, which in the area of mechatronics would be skills in developing products such as robots, or parts thereof. Experimental learning implies interactive communication since this approach is based on hands-on exercises, individual experimenting and practical work.

Papers G, H, and I describe attempts at integrating the experimental approach into mechatronics education. The basis for this is a concept for experimental learning in mechatronics, the mechatronic learning concept.

Experimental approach is defined in this thesis as an approach to learning where the student is doing such things as performing experiments or executing hands-on work — basically, any approach that, unlike simply reading textbooks and listening to lectures, also contains some practical dimension.

In the literature, 'experimental learning' is mostly used as an umbrella term to cover aspects of learning such as field work, studies abroad, and other learning activities that engage the learner directly (Newell, 2001; Cantor, 1995). Newell (2001) presents a definition of experimental learning:

> "If we begin to think of experimental learning as involving contrasting perspectives from the classroom and from another real world setting, not just the application of theory to practice through active learning, then its full potential can be realized."

One possible explanation for this is that the real world setting provides reason, motivation, and purpose for the theory and its applications. Education ought not to be only about theory and the application of the theory, but also about the preparation for future work which a real world setting can provide.

7.1 Motivation for experimental learning

One conclusion of the didactical analysis is that the preferred mode of communication is an interactive one. Interactive communication can be facilitated by several different means, but the most important aspect is that of feedback.

A number of approaches to learning have already been discussed in this thesis, and several of them are relevant to the issue of interactive communication:

Constructivist approach to learning The constructivist approach to learning is based on the notion that knowledge is created by adaptation, when a conflict appears between inner reasoning and the outer world. Experimental learning that focuses on the interaction with a real world setting is clearly compatible with this approach.

Problem based learning Problem based learning originally evolved to address lack of skills in medical education, with the goal of transforming educational programs from a formal legitimacy toward a functional legitimacy. It is based on five basic ideas: active learning, constant assessment, emphasis on meaning and not facts, freedom and responsibility, and access to resources. All these ideas are in line with the experimental approach; interactive communication and interaction with the real world.

Product based learning Product based learning is even more strongly based on a functional legitimacy than problem based learning, since it requires projects to be related to real products — a successful project delivers a new product. It is not hard to see how effectively this can be implemented using an experimental approach.

Collaborative learning Collaborative learning is not directly related to experimental learning except in that it stresses skills, such as teamwork and communication, that are more relevant to a professional, industrial, work-like setting than to traditional higher education. Moreover, as long as aspects such as project management and presentation techniques are integrated into a course, no conflict between the two approaches need occur.

International collaborative learning The major difference between collaborative learning and international collaborative learning is that the expansion into the global arena more closely mirrors the current situation in most larger companies.

Learning as a social activity Learning as a social activity requires that consideration must be made of such aspects of professional life as teamwork, management, communication, and human considerations. This setting can be viewed as an expansion of collaborative learning in which social interaction is given greater importance.

Design thinking Design thinking represents a move from an analytical way of thinking toward a more synthesis-based way of thinking, manifested, for example, by a change in focus from analysis of products to skills in product development. This approach has a lot in common with product based learning, and again it is not hard to see its relevance to experimental learning.

7.2 Experimental approaches

In all approaches described in the previous section an experimental approach can be legitimized. There are also more traditional reasons for integrating experimental approaches into engineering education (Jackson et al., 1979; Flink, 2001):

- Preparation for future work. Applied subjects require functional skills, both related to problem solving and to mastering the subject itself.
- Creating variation. Variation in learning approaches helps students to approach a subject from different viewpoints.
- Increasing the number of possible learning modalities. Different students prefer different approaches, and while some students are well-suited to learning from lectures, others are more eager to perform experimental work.
- Enhancing motivation.

These reasons, together with the motivating factors laid out in the previous section, provide legitimacy for applying experimental approaches to mechatronics education. Since the didactical analysis also implies an exemplifying selection of the subject, it can be concluded that the aim of an experimental approach ought to be to focus on building real products in a setting of product based learning in order to prepare for a future career.

Building real products

Three implementations of the experimental approach will now be described. All three versions aim at enabling students to design and build mechatronic products, or at least prototypes thereof.

The first implementation, project based courses in mechatronics, has been touched upon previously when discussing international collaboration. The second implementation, the ‘mechatronic learning concept’, was developed as a more general set of tools to facilitate experimental approaches and fast prototype design in mechatronics education. The third implementation, ‘the lab in your pocket’, is a subset of the mechatronic learning concept chosen for a particular introductory course in microcontroller systems.

When turning the focus to these implementations and the papers describing them, it is important to keep in mind that they represent only a tiny fraction of the many possible implementations of experimental learning.

7.3 Project based courses in mechatronics

This implementation was described in the previous chapter during the discussion of international aspects of mechatronics education. The idea is to create a capstone course in which students apply their knowledge and skills in mechatronics to design and build a prototype for a product that ultimately has the purpose of satisfying either a particular need or a particular corporate sponsor.

The main course studied in this thesis, an advanced course in mechatronics at KTH, is attended by approximately 40 students each year. The students are divided into about three teams, each supervised by a project coach from the faculty. The course is problem and project based. The problem is introduced to the students around October, and the teams are expected to produce a fully functional prototype by the beginning of June the following year. During the course the teams are organized in four phases: conceive, design, implement and operate, in accordance with the CDIO initiative presented earlier, and responsibilities are shared among the students. (Further details and discussion of the course can be found in paper D.)

Although this is only a single course at a single university, it does resemble other current capstone courses in most aspects. From the point of view of this thesis, its most important feature is that due to the large investment of student time and the substantial involvement of the corporate sponsor, it provides a considerable amount of funding, time, motivation, and manpower, allowing the conception, design, and implementation of a fairly complex and actually functioning prototype of a mechatronic system or products.

7.4 The mechatronic learning concept

The second implementation that will be discussed is the mechatronic learning concept, a modular experimental system consisting of hardware, software, design, and educational modules for the fast prototype design of mechatronic products. The purpose of the mechatronic learning concept is to provide a set of building blocks, relating to software as well as hardware, to make up the elements of a mechatronic product.

The hardware and software modules are detailed in Figure 7.1. They consist of a matrix of microcontroller modules, communication interfaces, applications, compilers, and operating systems. The basic idea is that all modules should be compatible with each other, and it should be easy to design new modules, so that a mechatronic prototype system can not only be easily assembled using the existing modules, but also easily integrated with newly-designed modules.

Papers G, H, and I introduce the mechatronic learning concept and present an analysis aimed at verifying the hypothesis that the concept facilitates experimental learning in mechatronics. Such facilitation comes about via fast prototype design, parallel development processes, and perhaps most importantly by the accumulation of knowledge, hardware, software, and experience from earlier projects, experiments, and courses. Further, the papers focus on the integration of new modules — specifically, a wireless module, a main sensor module, and a memory module — to further prove the hypothesis that advanced technology can easily and at relatively low cost be integrated into experimental mechatronics education to provide a cumulative framework for future courses and projects.

7.5 The lab in your pocket

'The lab in your pocket' project was created to implement both an exemplifying selection and an interactive communication in a course in microcontroller technology. The basic ideas of 'the lab in your pocket' concept are the following:

- each student has constant access to his/her own set of laboratory equipment;
- the laboratory equipment can be used at any location, at any time, with the only requirement being access to an ordinary PC;
- the equipment is sufficient to allow each student to perform all the laboratory work required by the course;
- the equipment promotes open-ended solutions, meaning that all experiments are flexible enough to encourage creative solutions;
- the total cost of all sets of equipment does not exceed the cost of traditional laboratory facilities.

The laboratory equipment consists of an Infineon C167-CS microcontroller, an I/O module with a LCD display, keyboard, buttons, and LEDs. Also, a DC motor, a number of sensors, for example accelerometers and temperature sensors. Technical manuals, C compilers, and examples of programs and projects are also provided.

In an evaluation of this project it was found that in comparison to a traditional experimental course the participating students received considerably higher grades, the students spent considerably more time on experimental work, and the faculty spent considerably less time on supervision (Grimheden and Hanson, 2003c), all adding up to a lower total course cost for the university.

7.6 Conclusions regarding experimental learning in mechatronics

Analysis of these three implementations of experimental approaches to learning in mechatronics points toward the following conclusions:

- An extended capstone course in mechatronics can enable student teams to design and build functional prototypes of real products. This is in line with the functional legitimacy of mechatronics, as well as an exemplifying selection and an interactive communication. The focus on designing products rather than involving students in projects is consistent with the ideas behind product based learning, an approach which further supports functional legitimacy.

- The mechatronic learning concept enables students to quickly design fast prototypes of mechatronic products. The mechatronic learning concept has been tested in one capstone course, according to the above, and proved advantageous in the design of a prototype for a balance prosthesis. From an educational point of view, the educational process benefits primarily from that the mechatronic learning concept not only provides a platform for prototype design that allows a fast prototype to be assembled within a few weeks, but it also encompasses the concept of accumulated knowledge; any one project can both benefit from previous projects and provide functional modules for use in future projects.

- The 'lab in your pocket', a subset of the mechatronic learning concept, has advantages relating both to actual interdisciplinary learning and to student motivation. Individual and mobile access to an advanced set of experimental laboratory equipment can increase knowledge, skill, and understanding in mechatronics. Also, from an economic point of view, these portable equipment sets appear to be more cost-effective than traditional laboratories — in part because the need for teaching assistants and indeed supervision in general is reduced due to increased communication between students.

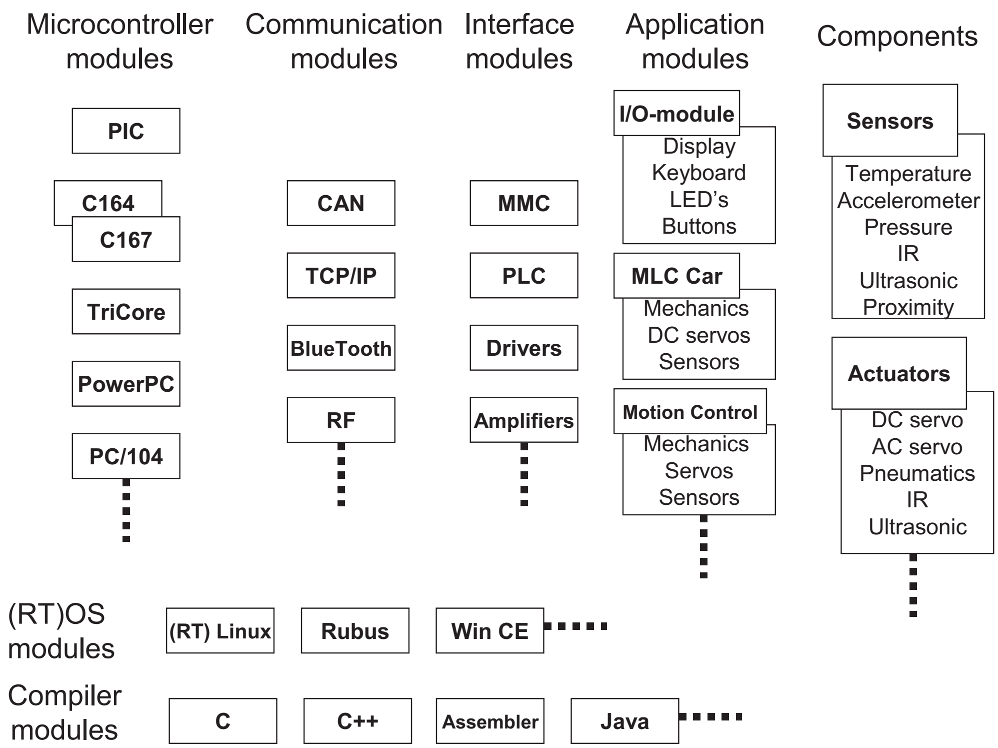

Figure 7.1: Examples of hardware- and software modules developed for and used in the mechatronic learning concept

Chapter 8

Conclusions

The aim of this thesis has been to help bridge the research gap between the area of engineering education and the specific subject of mechatronics. This is accomplished with an analysis of the subject of mechatronics according to current research in the area of subject matter education, with implementations of the results of that analysis — firstly in the context of international collaboration and secondly using the experimental approach to learning — with examination of the outcome of these implementations.

The framework chosen for the analysis of mechatronics was a didactical one based on four questions; the questions of identity, legitimacy, selection, and communication.

Research methodology primarily consisted of case studies, action research, and to some extent an ethnographic approach. The main tools used for empirical data collection were focus groups, interviews, and documentation of student activities, although in one case quantitative questionnaires were also used.

Background and context have been provided in the form of an overview of current trends in engineering education, both to serve as a foundation for future work and to present the possibilities inherent in an exemplifying selection and an interactive communication in the perspective of a modern way of viewing engineering education.

8.1 Results

According to the analysis of literature and the empirical findings presented in this thesis, the identity of the subject of mechatronics is thematic, its legitimacy is functional, its preferred method of selection is exemplifying, and its preferred communication method is interactive. In brief, this means that mechatronics is not a disciplinary subject like most traditional academic subjects but is rather defined by example, viewed as an inter-disciplinary subject, and organized differently in different universities. Its functional legitimacy means that the surrounding society requires functional skills to a greater extent than in more traditional subjects with a formal legitimacy. A hiring industry, for example, might ask for skills related to the themes of mechatronics, such as skills in designing robots and controllers, rather than specifying important courses.

The questions of selection and communication are strongly linked to the teaching of the subject, and should be considered in the light of the previous two questions. A thematic identity and functional legitimacy implies an exemplifying selection and an interactive communication. In brief this means that the best way to teach the subject is to choose to teach ‘everything of something’ rather than ‘something of everything’, and to use an experimental approach that enables students to choose their own ways of approaching the subject.

The primary result presented in this thesis is the didactical analysis of the subject of mechatronics and the study of two possible implementations, the international collaboration and the experimental approach. The results of this didactical analysis are further employed in a discussion on the evolution of the subject of mechatronics, using a theoretical model for the evolution of an academic subject.

International collaboration and experimental learning

The didactical analysis answers the questions of ‘what’ and ‘how’; ‘what is mechatronics and how should it be taught?’. Following on from this are two possible implementations of the ‘how’ — international collaboration and the experimental approach. These both support the exemplifying selection and the interactive communication, primarily in the sense that they stress the need for a number of different modes in which students can approach the subject.

Firstly, it can be concluded that international collaboration can produce enhanced disciplinary learning, improvement in other skills, increased awareness of cultural differences and different educational systems, and an overall increase in motivation.

Secondly, it can be seen that the experimental approach to mechatronics education is beneficial in that it enables students to focus on the skills required by functional legitimacy and also can result in higher motivation and higher grades.

8.2 Future work

The results and discussion presented in chapters five to seven raise several possibilities for further research. The didactical analysis of the subject of mechatronics has been tested by the author on three different subjects — mechatronics, embedded systems, and design engineering — but in all three cases the results of the analysis were very similar due to the similar nature of the subjects; all are relatively new, are focused on synthesis rather than analysis, are applied rather than theoretical, and have high industrial relevance. To properly establish the usefulness of the didactical method it would be necessary to apply it to more disparate subjects with more varied identities and legitimacies.

Concerning the study of the evolution of the subject of mechatronics, testing the model on other subjects would provide opportunities for refining and evaluation.

Finally, further evidence for the benefits of international collaboration and the experimental approach to mechatronics education would be most valuable.

Some editors and reviewers have expressed a desire for quantitative data to establish the relation between, for example, enhanced interdisciplinary learning and international collaboration. Such an approach is complicated by the relative lack of reliable methods and tools for measuring interdisciplinary learning. One possible approach would be to further investigate the effects of university education on the hiring industry, for example to study mechatronics engineers after one, five and ten years in mechatronics companies, and measure the utility of their knowledge and skills.

8.3 Concluding remarks

This thesis shows that mechatronics is a special subject, not easily understood or taught. To be mechatronic is to be synergistic, and to be synergistic generally demands expertise in all underlying subjects. The conclusion of this thesis is that this requires a non-traditional education where the focus is on training rather than studying, coaching rather than teaching, experimenting rather than reading, working together rather than apart, and being mechatronic rather than studying mechatronics.

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