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LEARNING MECHATRONICS

IN COLLABORATIVE, EXPERIMENTAL AND INTERNATIONAL SETTINGS

MARTIN GRIMHEDEN

STOCKHOLM
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LICENTIATE THESIS
DEPARTMENT OF MACHINE DESIGN
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Akademisk avhandling som, med tillstånd av Kungliga Tekniska Högskolan i Stockholm, framlägges till offentlig granskning för avläggande av teknologie licentiat examen måndagen den 9 december kl. 10.00 i sal M3, adress Brinellvägen 64.

Learning Mechatronics
In collaborative, experimental and international settings

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Abstract

The academic subject of mechatronics has been defined previously in numerous publications. This study aims at analyzing mechatronics by using categories developed within the educational science of *Didactics*. The result of the analysis, that relies on data from mechatronics education at KTH and other universities, shows that the identity of mechatronics can be described as thematic, and the legitimacy as functional, which gives implications for the questions of communication and selection: what should be taught, and how. This is combined with a study of the evolution of the subject of mechatronics, where it is possible to see the gradually changing identity, from a combination of a number of disciplinary subjects to one thematic subject.

The first part of the thesis concludes that mechatronics is autonomous, thematic and functional. Teaching and learning mechatronics according to the identity and legitimacy of the subject benefits from collaborative, experimental and international settings. The functional legitimacy today requires the collaborative and the international setting, meaning that the mechatronics employer requires these skills when employing a mechatronic engineer. Further, an exemplifying selection requires the experimental setting, in particular when comparing a representative selection with the reproduction of knowledge, and an exemplifying selection with the creation of knowledge.

To conclude, there are a number of important aspects to take into account when teaching and learning mechatronics. Three of these aspects, collaborative, experimental and international are suggested as important, and also a direct consequence of the identity of mechatronics. This thesis shows that these three aspects are indeed possible to integrate into mechatronics education, which will benefit greatly from this.

Key words/phrases: Mechatronics, engineering education, collaborative-, experimental-, distributed- and opportunity learning, prototype design

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During the latter period of my research, I received financial support through the Mechatronic Learning Concept (MLC) project, which in turn is supported from several sources, including KTH and the Council for the Renewal of Higher Education in Sweden. Some aspects where supported by the Massachusetts Eye and Ear Infirmary, Harvard Medical School, and the NeuroMuscular Research Center at Boston University, and I am greatly thankful to Dr. Conrad Wall III and Dr. Lars Oddsson for providing a framework for conducting research in mechatronic prototype development, as well as a Boston Getaway.

Further, the Mechatronic Learning Concept has given valuable connections at numerous universities, conferences and companies, and for this I am grateful to my co-designers of the MLC, namely Mikael Hellgren, Avo Kask and Martin Törngren at KTH, former colleague Tobias Lundberg and Per Engdahl at Infineon.

During the studies performed these three years, I have been interviewing and observing students, intervened and interfered in courses, and basically asked students repeatedly to provide me with their time. Even though most students have a rather full schedule, I have not once been declined help from a student. These students, approximately 200 during three years, have on the contrary taken me to numerous lunches and dinners, athletic training sessions, parties, exam trips to exotic countries and lively discussions. I am forever grateful for their support, and I know they will all become, or already are, the best mechatronic engineers there are.

Finally, I'd like to express my gratitude to the three persons most important for my research: My employer, Hans Johansson, for providing time, space and resources; My mentor, Sören Andersson, for being the ideal mentor, and my supervisor, Mats Hanson, for his great enthusiasm, engagement and trust.

Stockholm, 2002-11-08

Martin Grimheden

Included Articles

1. Grimheden, M. & Hanson, M. (2001). What is Mechatronics? Proposing a Didactical Approach to Mechatronics. Proceedings of the 1st Baltic Sea Workshop on Education in Mechatronics, Kiel, Germany.

2. Grimheden, M. & Hanson, M. (2001). Mechatronics – the Evolution of an Academic Discipline in Engineering Education. Presented at the 1st National Mechatronics Meeting, Stockholm, Sweden. Submitted for publication.

3. Grimheden, M. & Hanson, M. (2002). Collaborative Learning in Mechatronics with Globally Distributed Teams. Accepted for publication in International Journal of Engineering Education.

4. Grimheden, M. & Strömdahl, H. (2002). The Challenge of Distance: Opportunity Learning in Transnational Collaborative Educational Settings. Submitted for publication.

5. Grimheden, M. & Hanson, M. (2002). Providing a framework for prototype design of Mechatronic systems – A field study of an international collaborative educational project using the Mechatronic Learning Concept. Proceedings of the 3rd European Workshop on Education in Mechatronics, Copenhagen, Denmark.

1. Introduction

The subject of Mechatronics emerged in the literature during the late 1960's, and has since then been established as an academic subject that's researched and taught at a large number of universities worldwide. During these almost 40 years the subject has evolved through a series of redefinitions, starting with the idea of electrification of mechanisms, to the current point in time where the concept of synergy is encompassed.

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

The quotation above represents a milestone in this evolution, the publication of the first referred Mechatronics journal, IEEE/ASME Transactions on Mechatronics, where the authors agreed upon the definition of Mechatronics quoted above. The definition of the subject is still constantly debated, and other definitions together with the one used in this thesis are presented in the first appended paper (Grimheden & Hanson, 2001a). A milestone in the evolution of Mechatronics at the academic community in Sweden is illustrated by an anecdote that represents the birth of Mechatronics at KTH, the Royal Institute of Technology. The professor in Machine Elements, Jan Schnittger, returned to KTH in 1976 from a visiting professorship at Stanford University. He brought back a microcontroller, an Intel 8008, and declared: "This is a machine element". Today, 26 years later, the Mechatronics Lab constitutes the largest group within the department of Machine Design, with an established research- and educational program (Wikander, Törngren, Hanson, 2001).

Even though most Mechatronicians are most content with this definition, there exists a lively discussion regarding the next steps in the evolution, *what will come after this?* As one easily can imagine, the discussions in this matter are quite divergent, with some strong tendencies towards an expanded concept of synergy, for example the synergistic integration of mechatronic systems networks or the development of conscious systems that requires the encompassment of areas such as biology (Cotsaftis, 2002). To further set the stage for this thesis, the study of this evolution raises questions in terms of:

What's so special with the academic subject of Mechatronics, and how does one learn and teach this field? Is the subject really special at all, and is it really necessary to treat this subject different than others?

My humble standpoint is that *it is,* and I hope that this thesis will prove my hypothesis.

Outline of the thesis

This thesis will explore the idea of learning mechatronics in a series of five steps, each accentuated by an appended paper. The first step focuses on the use of concepts developed within the educational science of *Didactics* to analyse and describe the subject of Mechatronics. This is based on several studies undertaken at the Mechatronics Lab at KTH, which are used to analyse the identity and legitimacy of the subject, and as a base for a discussion regarding the questions of selection and communication related to the subject. In the following introduction of this thesis educational *Didactics (didactical approach)* will be defined since it is used somewhat differently in central European and Nordic countries compared the Anglo-Saxon countries.

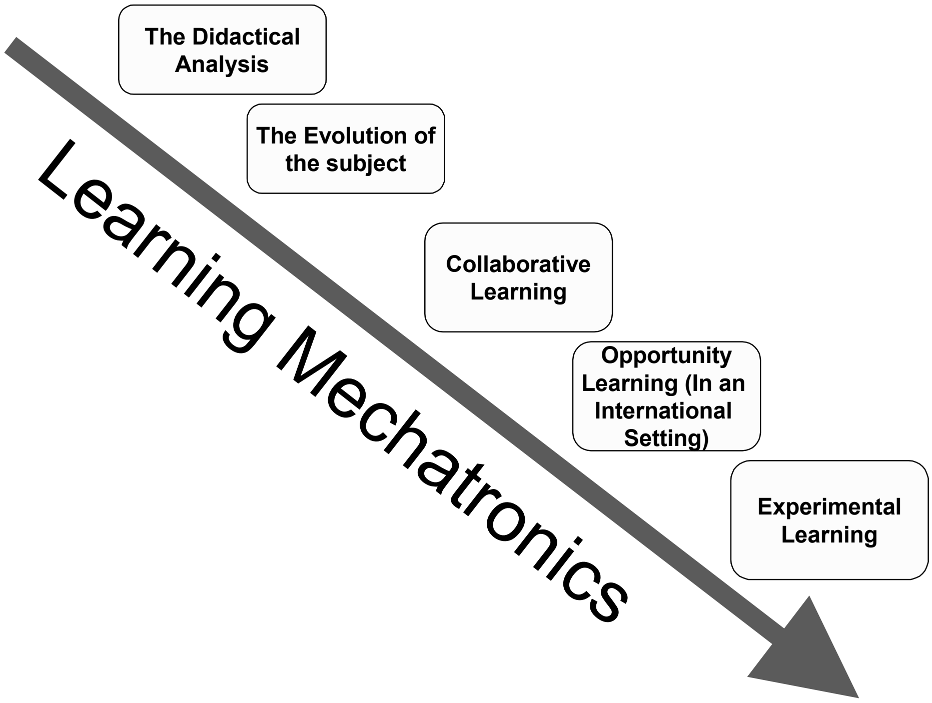

Figure 1. Illustrating the theme of the thesis and the five appended papers

In the second step, a model to describe the evolution of the academic subject of Mechatronics is introduced. This model is based on a comparative study of a number of universities teaching Mechatronics, together with the *didactical approach* used in the first step. The third and fourth steps explores the idea of collaborative learning in Mechatronics, first by focusing primarily on collaborative learning in Mechatronics in particular, and secondly, in the forth step, on collaborative learning in general, but with a focus on international collaboration. Both these steps are based on field studies undertaken at KTH and Stanford University, within courses in Mechatronics and Design Innovation.

The fifth and last step focuses on one aspect of learning in Mechatronics, the idea of using prototypes in Mechatronics education. This idea is motivated primarily on the results from the first two steps, the identity and legitimacy of the subject, and the need to use an exemplifying selection and an interactive communication based on the thematic identity and the functional legitimacy. The purpose of this fifth step is basically to propose, and argue for, an approach for fast, flexible and easy prototype design within Mechatronics education, based on accumulated knowledge and facilitated by a concept introduced as the "Mechatronic Learning Concept". Before introducing these five steps a brief introduction to the theoretical framework used in this research will be given.

2. Theoretical Framework

The theoretical base for this thesis is gathered from previous research done in a number of different fields, ranging from educational psychology to the sociology of knowledge. The research in education roughly focuses on three different levels, with different aims and backgrounds. Research on education on a society level is undertaken within the educational sociology, where the focus is on the relation between the design of the educational system and the society. If the focus is on the educational situation, contents and processes, within a particular subject, the field is defined as subject matter education. In the central European and Nordic educational research traditions *Didactics* is used, and in this thesis *Didactics* is used to describe subject matter education studies even if *Didactics* in the Anglo-Saxon traditions have the distinct meaning of "systematic instruction"[1].

The third level focuses on the individual learner, and is defined as educational psychology. The purpose of the research undertaken within this field is to understand the learning process, within a social, situational and individual setting, and in this thesis is referred to mainly when describing the learning processes identified.

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[1] According to Encyclopaedia Britannica

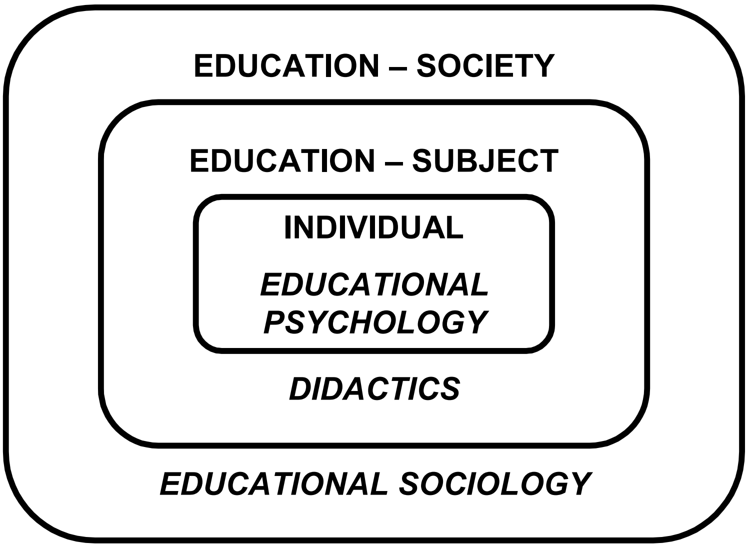

Figure 2. The three dimensions of educational research (after Dahlgren, 1990)

To illustrate each of the three dimensions, a brief introduction to previous research in each field will be presented. The intention is not by any means to cover all previous research in each field, only to provide enough background to appreciate the various perspectives.

Didactics

To move from the general educational sciences towards subject matter education requires a brief introduction to the terms used.

The term *Didactics* emerged in the literature at the beginning of the 17th century, and was at that time translated with the German word "Lehrkunst", the art of learning. One of the first users of the term was John Comenius, in his publication Didactica Magna from 1657. (Comenius, 1999) Originally the idea of the didactic field was that all teaching required it's own methods, and that every discipline had it's own system and followed it's own logics. If, through research, the disciplinary logic could be determined, the appropriate teaching would be determined by presenting the disciplinary contents according to the disciplinary logic. Subsequently, the original didactical researchers started to uphold that education was disciplinary independent, and followed it's own logic. Even though the subject didactics dominates today, the discussion is still active; whether the preferred approach is the general, or the subject didactics. Since the 17th century, the area of didactics has evolved, basically from the original idea to encompass all educational aspects to focus on particular knowledge and skills (Alerby, Kansanen, Kroksmark, 2000).

As described earlier the term subject matter education is used to explain the term didactics, or rather, subject didactics. In the German and the Swedish language, 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 a discussion has taken place to clarify the English definition of this term there is a need to further press the original meaning of "didaktik" (Kansanen, 1995). Hudson, Buchberger, Kansanen and Seel (1999) proposes that the term "didaktik" cannot be understood without the concept of the German term "Bildung", or "Bildning" in Swedish, a concept that could be translated with creation, formation, or erudition[1]. The concept of "Bildung" encompasses the social context, the shaping of the personality, and the learning process in interaction with previous knowledge and experiences, as well as the interaction with others. The concept of "Bildung" 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*" (*ibid.*).

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

Dahlgren (1990) proposes that a didactical analysis of a subject could 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 three categories given by Dahlgren are used, with the

[1] According to The American Heritage Dictionary of the English Language

addition of a fourth, a question of identity (but presented here in a different order).

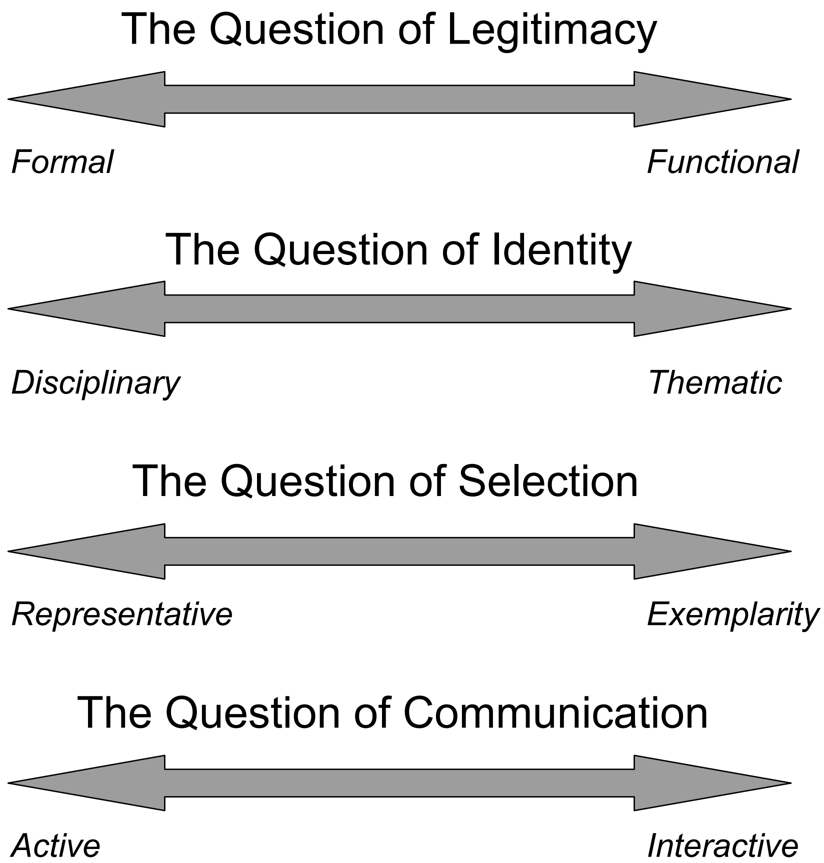

Figure 3. The four didactical questions, partly adapted from Dahlgren (1990)

The first is the question of legitimacy. This question is connected to the relation between the actual outcome of the educational efforts and the nature of the demand that is put upon the student's abilities by the society, or the industry. The demand from the society and/or the industry is categorized into two aspects, either formal or functional, and the relation between the outcome and the nature of the demands is related to formal legitimacy or functional legitimacy. In a simplified model the formal aspect deals with formal knowledge; knowledge that is commonly found in textbooks and is supposedly read and understood by students. The functional aspect deals with skills; skills that is not usually learnt in textbooks or during lectures, skills that students develop during hands-on exercises, laboratory experiments or by trial and error. To give an example, a teaching situation, in for example a foreign language, could either focus on the ability to correctly spell words, or on the ability to communicate. The demands from the society could either be formal, to specify which words the students should be able to correctly spell, or functional, that the students should be able, for example, to order a beer at a German Bierstube.

The question of identity is second. A subject's identity could be viewed as either disciplinary or thematic. The classification of the identity is not difficult to make, and to study the change of the identity within a specific subject could be more revealing. When new areas are introduced and when the evolution of knowledge in a particular subject moves forward, the classification of the identity usually changes, starting with a newly created thematic identity, and slowly settling into a disciplinary identity. To exemplify this question a number of subjects that are usually referred to as cross disciplinary, such as systems engineering, cognitive science etcetera usually originates from a theme such as systems or cognition, which runs through a series of subjects such as mathematics, philosophy, psychology. In this case the subject of systems engineering would be classified as thematic, and the subject of mathematics as disciplinary.

In this thesis a distinction is made between the first two questions, and the last two, with the hypothesis that the questions of identity and legitimacy strongly affects the answer to the last two questions, the questions of selection and communication. The question of selection within a subject can be viewed in the perspective of two extremes; on one side the more traditional standpoint is represented by the notion that in the teaching of a subject, the selection of the contents should be represented, meaning that the contents should reflect the entire subject in a broad perspective. The opposite extreme is represented by the notion of exemplification, a perspective in which the subject rather is exemplified than represented. To further clarify this question the term horizontal representation is often used, which in the case of a subject like computer science could be equal to a curricula that spans over the entire field, and where the students study general knowledge and principles related to computer science in general. The opposite, exemplification, could be described as a vertical exemplifying selection, which in the case of computer science could lead to a curricula where the students study one computer platform, or one programming language, but to a great depth. The underlying philosophy with the vertical exemplarity is that knowledge and skill in one particular language, or platform, gives general knowledge and skills to facilitate learning in other nearby languages and platforms, but is certainly not an uncontested viewpoint.

Finally, the question of communication can also be described by using two extremes: the question of communication can be described in a perspective of action – where teaching is action. The question of communication is then a question of how the teacher should act, how the teacher should act in relation to the material, how the teacher should act towards the students and so on. The opposite can be described as the perspective of interaction. Interaction can be explained as action based on feedback, action from the teacher that is based on the output from the students, or action that is based on an insight of the students current individual learning processes.

Sociology of Scientific Knowledge

Even though the scope of this thesis does not encompass education on society level, the field of sociology of knowledge, and in particular the sociology of scientific knowledge, and the area of social constructions of technology can provide understanding of the social construction of an academic subject, such as mechatronics, and how knowledge is created within the subject.

In 1976 David Bloor published his "Strong Program" (Bloor, 1976/1991), which represents a new era within the sociology of knowledge. Prior to the program, the sociology of knowledge was limited to the area of natural sciences, with a rationalistic perspective. The researchers where assumed to be rationalistic, as their activities, and their results where deemed reliable. This rationalistic view on knowledge is based on the idea that knowledge is acquired through reason, and knowledge claims can only be justified by reason and sense (Starrin & Svensson, 1994). The Strong Program, as defined by Bloor, is a structured research program that aims at a systematic understanding of the scientific knowledge. This program is based on four tenets: causality, impartiality, symmetry and reflexivity. The most quoted is the tenet of symmetry, which implies that sociology of scientific knowledge "would be symmetrical in its style of explanation. The same types of cause would explain, say, true and false beliefs." (Bloor, 1976/1991; Collins, 1981; Collins, 1985/1992).

The tenet of symmetry is not limited to impartiality and neutrality; the approach is rather to keep a relativistic view on the action undertaken by the scientific researcher, without assigning values to the action. As a result the analyst is not allowed to use later discoveries or his/her own knowledge in the scientific field to explain the action undertaken by the researcher. The tenet of causality is, with another explanation, replacing the teleological perspective, as defined by Aristoteles.

Harry Collins expands the Strong Program into the "Empirical Program Of Relativism", EPOR, also as a plan for action, or a research methodology to understand the creation of knowledge. (Collins, 1981; Collins, 1985/1992). EPOR continues with the idea of flexibility of interpretation, meaning that all facts can be interpreted differently, and that nature is not sufficient to explain creation of knowledge. The strategy of EPOR is to find and identify a flexibility of interpretation related to a particular field or phenomena, and to find the mechanisms that transfers the controversies and conflicts to a status of closure, which implies that the interpretations have converted, or been reduced, to one.

If applied to the subject of mechatronics, the status of closure has not yet been reached since the definitions and views on the academic subject of mechatronics varies according to university, journal and interpreter, in particular if comparing to other thematic and cross disciplinary academic subjects like solid state mechanics, where the flexibility of interpretation today is less widespread. In the case of an academic subject, the mechanisms that transfer the controversies are primarily scientific journals and conferences, and the ability to reach global closure is dependent of the discussions held in these forums.

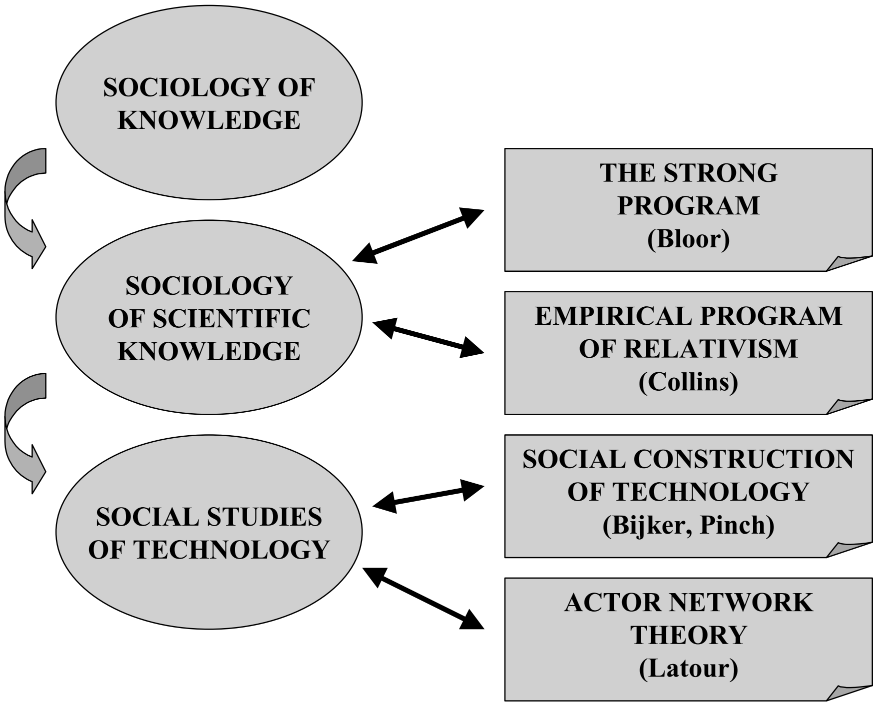

Figure 4. Moving from the sociology of knowledge to the social studies of technology and samples of their respective research programs (Grimheden, 2002)

Social Construction of Technology

David Bloor and Harry Collins focuses on the sociology of scientific knowledge, and the research undertaken and presented here forms a base for the later developed field of social studies of technology. Steve Woolgar (1991) presents a concept "to study technology as a text", as a possible approach to switch the focus from science to technology. To study technology as a text can be achieved if, for example, comparing the design process of the technology with the writing of a text, and the use of the technology with the reading of a text. How the reader interprets the text, or uses the technology, is dependent of the reader, or user.

The phenomenon of closure, as mentioned earlier, provides an elegant way to understand the processes of social constructions of technology. This concept was used as one of four bases in the program presented in

1984 by Trevor Pinch and Wiebe Bijker, called SCOT for Social Construction Of Technology (Bijker, 1995; Pinch, 1996). In short the program introduced by Pinch and Bijker focuses on the interpretation of artefacts, that artefacts is underdetermined by technology to functionality and use. The variations in interpretations are identified, and the process leading from variations to stability, and then further to closure, is used to describe the social construction of the artefact.

Another program within the social studies of technology is provided by Latour (1992a; 1992b), and introduced as an actor network theory. Latour expands the concept of symmetry to also encompass the artefacts, and the artefact becomes an actor in a network that interacts with other individuals and groups. As a consequence of this Latour introduces the concept of inscription, meaning that an artefact by it's designer is inscribed with a pattern of use, or a pattern that reflects the interpretation of the society, without going as far as technological determinism.

When combining the theoretical frameworks of didactics and sociology of scientific knowledge, an approach to understand both the nature of the subject of mechatronics, the evolution of the subject, and the social construction of the subject can be outlined. In the case of subjects like mechatronics the connection between the subject and the artefacts produced and analysed is strong since the artefacts often are used when communicating the nature of the subject, for example when integrating robotics into the mechatronics curricula and stating: "robotics is mechatronics". In this case the research programs presented above, like SCOT, where the variations in interpretations of the artefact is studied, shows that these illustrations often build on technological determinism and does nothing to help establishing mechatronics as an academic subject on a society level. On the other hand, an artefact that has reached a stage of closure among its users, could illustrate the subject with a great benefit.

A constructivistic approach to learning

The constructivistic approach to learning is based on subsets of research within the two fields of cognitive psychology and social psychology, and has it's roots within the epistemological questions Immanuel Kant faced during the late 18th century, questions based on the relation between objects in the so called outer world, and individuals awareness about these objects.

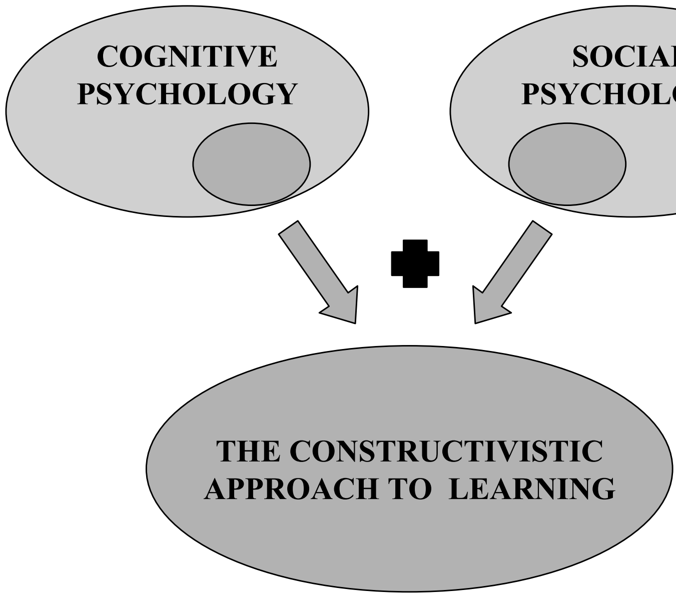

Figure 5. The constructivistic approach to learning is based on research undertaken partly within cognitive psychology and partly within social psychology (Piaget 1972; Vygotsky, 1978)

The modern approach to constructivistic learning is primarily based on research undertaken by John Dewey, Jean Piaget and Lev Vygotsky during the first half of the 20th century (Dewey, 1933/1998; Piaget, 1929; Vygotsky, 1987). The constructivistic theory of knowledge, as developed by Piaget, can be summarized into the following:

1. A person constructs his knowledge on the basis of his experiences

2. Knowledge is not equal to empirical sensory impressions

3. Knowledge is not equal to inner rational reasoning, independent of sensory impressions

4. Knowledge is a mental tool to understand the reality, and is constructed in interaction between sensory impressions and reason

5. Knowledge is (inner) cognitive structures that a person constructs through active interaction with the (outer) world

Piaget separates the dynamic and the structural aspect of learning, where the dynamic aspect deals with the driving force of learning, where the driving force originates from, while the structural aspect deals with the contents and nature of learning. Piaget describes learning as a process of equilibrium where the individual strives to remain in balance in interaction with the surroundings through the concept of adaptation. The surroundings adaptation to the individual is done through the concept of assimilation, where sensory impressions are added to existing structures of knowledge, a kind of additive learning. The opposite is defined by Piaget as accommodation, meaning that the individual is adjusting to the surroundings. These two processes, assimilation and accommodation, in combination maintain the process of equilibrium.

To illustrate the individual constructivistic approach, as outlined by Piaget, an example will be given[1]. In primary school a teacher is explaining the concept of geometry to a class of eight-year-old pupils. The teacher draws a square box on the blackboard, points on one corner, and declares, "This is a corner". When one of the pupils hears this, he associates (consciously or unconsciously) to the corners in the rooms at home. In a constructivistic approach to learning, the pupil has now expanded his definition of the term corner. Before, corner was equal to the corners in a house, but now a corner can also be the point where the lines that form a square meet. The pupil has assimilated an empirical sensory impression to his already existing structures of knowledge. To maintain the process of equilibrium, the balance, the pupils existing structures of knowledge has changed, through accommodation, and been adapted according to the new definition. The characteristics of the constructivistic approach to learning are primarily this constant assimilations and accommodations between existing structures of knowledge and the surroundings.

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

The constructivistic approach as described above is in literature referred to as individual constructivism (Marton and Booth, 2000) and differs from the approach that is based on the psychology developed by Vygotsky (1987) and is referred to as social constructivism. The social constructivism mirrors the individual constructivism and focuses on the outer actions as explanations for inner reasoning, instead of the opposite. Vygotsky describes the nature of the development of a child as changing from a biological to a social nature, and a key to understand learning in a social constructivistic approach is the concept of mediating, or pre-interpretation. In a comparison to the individual constructivistic approach, where the human development in terms of knowledge, is determined by our inner reasoning in relation to the surroundings, the development in a social constructivistic perspective is dependent of the interpretation into common and collective human activities.

To summarize the social constructivistic approach: All human acts are situated in a social practise. The acts made by an individual always origin in the individual's knowledge and experience, and in particular what the individual consciously or unconsciously understand regarding the demands, or allowance from the surroundings. (Säljö, 2000).

Studies of learning in higher education

The discussion related to the different perspectives on learning will be concluded with an introduction to a possible method to study learning processes, the intentional analysis. In educational research a large number of possible approaches to study learning exists, for example to study the process of learning as a phenomena. The choice of turning the focus to the intentional analysis is primarily based on previous experience.

The theoretical base for the intentional analysis builds on a philosophical theory of actions developed by von Wright (1971), a theory for the understanding of people's actions in relation to cognitive considerations and cultural contexts. The intentional analysis uses a method where people's actions are ascribed to a meaning, an intention (Wistedt, 1987; Halldén, 1982; Scheja, 1998).

To illustrate: within engineering education, evaluations and studies of educational results and learning processes often points out facts that students have variations in their approaches to a certain task or problem, but does not focus on the reason behind this. With the intentional analysis, an observed behavior can be assigned a possible meaning, not a definitive cause for the action, but a possible explanation. If this meaning, explanation, or intention, is put in relation to the context where situated, a more descriptive picture of the actual learning process, or variations in the learning processes, can be created.

Conclusions

Before turning the focus to the subject of mechatronics, and the application of the theoretical framework onto the subject, a brief conclusion of the perspectives of learning will be given.

1. The individual is within a cognitive context, built on previous experiences, knowledge and conceptions.

2. The individual is within a situational context, with conceptions about the current educational situation, for example what is expected of the student, which possibilities the situation gives etc.

3. The individual is within a cultural context, built on the academic culture, social culture, and general conceptions about the various subjects.

To fully understand, and characterize, learning in a particular subject, like mechatronics, there is a need to understand these three contexts.

3. Learning in Mechatronics

The first question to answer is *what is special about Mechatronics,* and an attempt is presented in the first appended paper, "What is Mechatronics – Proposing a Didactical Approach to Mechatronics" (Grimheden and Hanson, 2001a). This analysis is based on the previous described field of subject didactics, and 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, not disciplinary, and the legitimacy is identified as functional, not formal.

To further establish mechatronics with a thematic identity and a functional legitimacy, the second appended paper, "Mechatronics – The Evolution of an Academic Discipline in Engineering Education" (Grimheden and Hanson, 2001b), proposes a model for the evolution of mechatronics. This model is also based on a study of the subject of mechatronics, as taught primarily at European universities.

In combination, these two papers propose a connection between the questions of identity and legitimacy, and the questions of selection and communication, at least in the case of a thematic identity and a functional legitimacy. This proposed connection states that the thematic identity and the functional legitimacy imply an exemplifying selection and an interactive communication. The exemplifying selection is based primarily on the thematic identity and the functional legitimacy, and the interactive communication is based on the functional legitimacy. This connection is illustrated in the figure below.

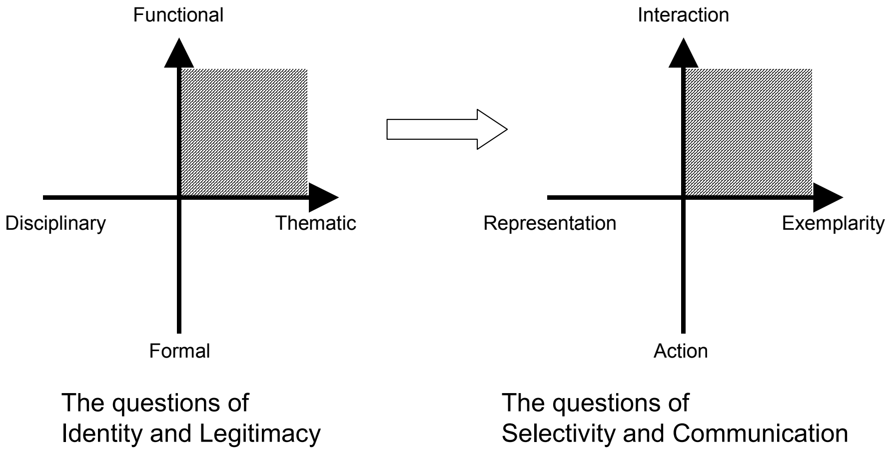

Figure 6. An illustration of the four didactic questions applied to the subject of mechatronics (Grimheden & Hanson, 2001a, based on Dahlgren, 1990)

The second paper, "Mechatronics – The Evolution of an Academic Discipline in Engineering Education", introduces a model to describe the evolution, or transition, of a thematic subject, or discipline, that originates in a number of disciplinary subjects, or disciplines. The model was introduced by Mats Hanson (Grimheden & Hanson, 2001b), and is illustrated in the figure below. The transition is done through a series of six steps, starting from an idea, or a theme that crosses boundaries of traditional subjects and disciplines. The second step is represented by the stage when the theme is used in a curriculum, or by individual students, where the student combines courses from various disciplines to cover the theme. The third step is represented by the stage when new interdisciplinary courses are designed, and the fourth step when new interdisciplinary programs evolve. The difference between the fourth and fifth stage is the creation of new organizations with an own culture independent of the original subjects and disciplines. The final sixth stage by is where the original disciplines have diminished completely in favour of the new thematic identity, which paradoxically is a discipline itself, but with a thematic identity. This sixth step however, is still open for research since the data used in this study does not cover this step.

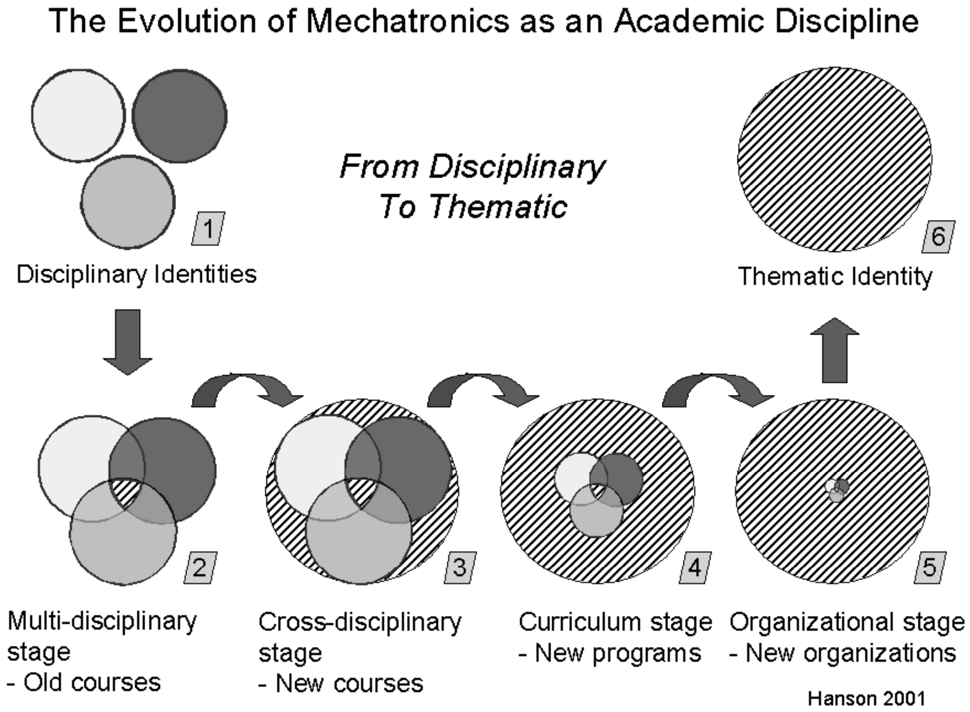

Figure 7. A model describing the evolution of a thematic academic discipline (Grimheden & Hanson, 2001b)

Collaborative learning in Mechatronics

The third paper, Collaborative Learning in Mechatronics with globally distributed teams (Grimheden and Hanson, 2002a), expands the questions of selection and communication to enrol the aspects of international collaborative learning in mechatronics. Due to the emerging issue of globalisation attempts have been made to internationalise the education in mechatronics (Wagner & Steinführer, 2001), and the third paper aims at investigating the possibilities of creating an international field for collaborative education in mechatronics.

To choose exemplarity in favor of representation can be a matter of choosing relevant and representative aspects, and projects, for the subject of mechatronics. Since the situation where the graduated mechatronics students in most cases will be active is an international market, in particular for Swedish students, an international educational setting is a more representative exemplification than a non-international (Maxwell, Geary, Dave, 2000), and also reflects the current identity of the subject of mechatronics.

The difference between an international and a local setting is primarily that the aspect of communication, mainly if seen in an interactive perspective, radically changes due to the increasing number of actors and teams in the system, and due to the fact that these actors represent different backgrounds, knowledge and cultures. Another major difference is the distance in time and space. When analyzing these differences in the perspective of the didactical approach, the choice of either an interactive communication, or a communication based on action is necessary to study further. If the interactive communicative approach is applied, a more favorable setting is acquired since this approach focuses on the current knowledge of each actor and his or her relative creation of knowledge instead of getting the entire group to reach a predetermined level of knowledge.

The research presented in this paper is based on a field-study of a collaborative mechatronic educational project between KTH and Stanford University, and the primary conclusions are, besides enhanced motivation for the students, signs of improved disciplinary learning, improved communicational skills and an education which better prepares students for future careers and work in a global area.

International collaborative learning in general

In the fourth paper a more general analysis is done of the same setting as described in the third paper, also based on a field-study of a collaborative educational project between KTH and Stanford University, but representing a study of an earlier project within the same courses. The purpose of this paper is to analyse the prerequisites and possibilities for a more general context than the subject of mechatronics. The paper presents a set of possibilities connected to the – with distance in time and space related – difficulties, to argue for a more flexible view where these difficulties, or disadvantages, are seen as learning opportunities.

From the empirical data outlined in this article certain signs are identified of both improved disciplinary learning and increased knowledge and skills in areas outside the current subject.

In previous research an approach to make a definitive categorization of advantages and disadvantages are often used when discussing distributed collaborative learning, in particular when discussing communication tools such as videoconferences and web-based distributed workspaces, but instead this paper proposes a model where the categorization is looked upon in a more flexible mode, and where the so-called disadvantages are used as opportunities in learning, and therefore used as learning tools.

The title, "The Challenge of Distance – Opportunity Learning in Transnational Collaborative Educational Settings" (Grimheden and Strömdahl, 2002) reflects the idea of accepting the distance as a challenge, with educational possibilities, rather than viewing it as an obstacle. From the empirical data used, a deductive reasoning regarding the results is not possible, but the conclusions are primarily the observed signs of enhanced disciplinary learning, increased knowledge and skills in areas related to the transnational setting, in spite of the so called distance related difficulties.

In the coming discussion about future research, this paper also presents a possible approach to study the students conceptual understanding of the project and their task at hand, and the process where the students construction of the project evolve through the constant descriptions, discussions and arguing, in particular with the distributed team members.

Experimental learning in Mechatronics

The fifth paper, "Providing a framework for prototype design of Mechatronic systems – A field study of an international collaborative educational project using the Mechatronic Learning Concept" (Grimheden and Hanson, 2002b), introduces a concept for experimental learning in mechatronics, a concept based primarily on the results from the didactical analysis of the subject, and the choice of using an exemplifying selection and an interactive communicative approach.

As a result of the didactical approach, a need for experimental equipment and prototype design in general is identified. A possible approach to accommodate this need is presented as the "Mechatronic Learning Concept", a modular experimental system consisting of hardware, software, design and educational modules.

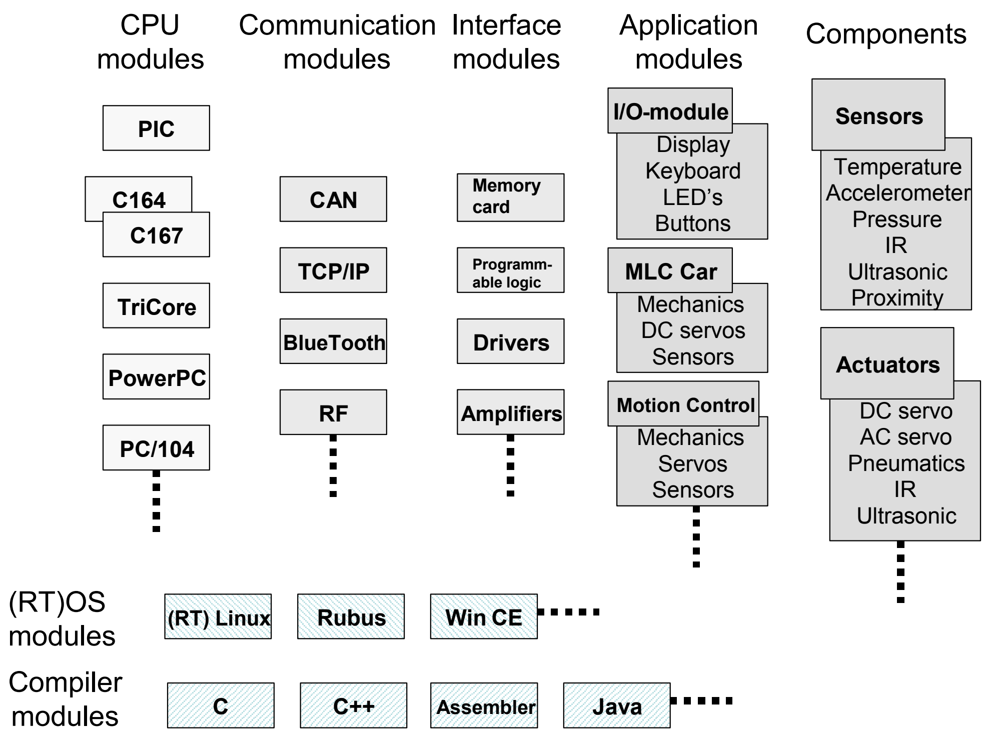

Figure 8. A selection of hardware- and software modules within the Mechatronic Learning Concept (Grimheden & Hanson, 2002b)

As shown in the figure above the hardware- and software modules consists of a matrix of microcontroller modules, communication interfaces, applications, compilers and operating systems. The basic idea is that all modules should be compatible and new modules easily designed, so that a mechatronic prototype system can easily be assembled with the existing modules, and integrated with newly designed modules.

The method used in the paper is based on a field study undertaken during the period from October 2001 to June 2002 within the framework of an educational project called the Boston Tea Party project (the BTP project). The BTP project involved twelve students, three project assignors and two faculty supervisors divided at three universities; the NeuroMuscular Research Center at Boston University (NMRC), the Massachusetts Eye and Ear Infirmary, a teaching affiliate of Harvard Medical School (MEEI), and the Mechatronics Lab at the Royal Institute of Technology (KTH). The field study was done within the framework of an advanced course in mechatronics given by KTH, the same course as described in the previous two papers.

The purpose of the BTP project was twofold: The project assignors focused on the development of a platform for conducting research in their respective fields, and KTH focused on the learning outcome for the students; basically the assignors provided the problems for the problem-based course, and the geographical location of the respective universities provided the international setting. The field study does not take the international setting into account and the implications on education are discussed in the previous papers.

The aim of the paper, and the research undertaken, is also twofold: The Mechatronic Learning Concept is introduced, and the analysis aims at verifying the hypothesis that the concept facilitates experimental learning in mechatronics. An example of this is by facilitating fast prototype design, parallel development processes, and perhaps most important, by accumulating previous knowledge, hardware, software and experiences from earlier projects, experiments and courses. Further, the paper focus on the integration of new modules; particularly a wireless module, a main sensor module and a memory module, to further prove the hypothesis – that advanced technology can easily and with a relatively low cost be integrated into experimental mechatronics education, and provide an accumulated framework for further courses and projects.

The results from the study shows that a team consisting of twelve students, with assignors, supervisors and assistants, could greatly benefit from the Mechatronic Learning Concept and as a result produce fairly complex systems in a short time frame. The process of integrating new technologies into mechatronics education is also facilitated greatly by the platforms provided by the concept, for example with a memory card that in a matter of days was integrated by the students into the matrix of hardware modules, an integration that was possible due to the existing modules that provided a basic platform.

4. Conclusions

The subject of mechatronics has been defined in various ways in numerous publications, and is here analyzed within a didactical framework. This is an analysis that builds on research that focuses on the educational situation, and has previously been done on several other subjects, but not before on the academic subject of mechatronics. The result of the analysis, that relies on data from mechatronics education at KTH as well as at other universities, shows that the identity of mechatronics is thematic, and the legitimacy is functional. When studying the evolution of the subject of mechatronics, it is possible to see the gradually changing identity, from a combination of a number of disciplinary subjects into one thematic subject.

In the introduction of the thesis a series of questions are stated:

What's so special with the academic subject of Mechatronics, and how does one learn and teach this field? Is the subject really special at all, and is it really necessary to treat this subject different than others?

The first two papers conclude that mechatronics is special, it's thematic and functional, in particular if compared to the subjects that mechatronics relies on, for example mechanical engineering, electrical engineering etcetera. When continuing the didactical analysis, a connection between this setting and the questions of selection and communication is identified, which implies that the subject of mechatronics should be taught with an exemplifying selection and an interactive communication. It is therefore necessary to treat this subject differently compared to other subjects.

How does one learn and teach this field?

Three keywords are extracted from this analysis, namely collaborative, experimental and international. To teach and learn mechatronics according to the selection and communication benefits from a collaborative, experimental and international setting. The functional legitimacy today requires the collaborative and the international setting, meaning that the mechatronics employer requires these skills when employing a mechatronic engineer. The exemplifying selection requires the experimental setting, in particular when comparing the representative selection with the reproduction of knowledge, and the exemplifying selection with the creation of knowledge.

To conclude, there are a number of important aspects to take into account when teaching and learning mechatronics. Three of these aspects: collaborative, experimental and international are suggested as important, and also a direct consequence of the identity of mechatronics. This thesis shows that these three aspects are indeed possible to integrate into mechatronics education, which will benefit from this.

Future work

In the introduction to this thesis a brief discussion was given regarding the future of mechatronics, the next logical step. This is not related to the evolution of mechatronics as an academic discipline described in the second paper, an evolution that describes the move from disciplinary to thematic, but the evolution that is related to the development of technology and breakthroughs in research. Even though the discussions related to this development are quite divergent, there are tendencies towards an expanded concept of synergy, the synergistic integration of mechatronic systems networks or the development of conscious systems.

These discussions leads to questions regarding the usability of the didactical analysis presented in this thesis, and to whether the analysis is possible to undertake constantly to better meet the future changes in the subject, as a method to keep the education constantly up to date and with an appropriate selection and communication. Further, analyses on other subjects, perhaps primarily on subjects with a similar identity and legitimacy, such as production engineering, thermodynamics etcetera, would be advantageous to undertake and study, to further establish the approach, and to investigate a more general usability.

A next step in future work is to make a more complete analysis of the subject of mechatronics in the other two dimensions outlined in the theoretical framework, on a society level and on an individual level. The analysis on a society level could be based on the theories of social studies of technology, and be used to further study the evolution of mechatronics as both an academic subject and as the more general concept of science. The individual level is necessary to understand the psychological aspects of individual creation, or construction, of knowledge, which will also be necessary to create a more thorough understanding of *Learning Mechatronics*.

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