

DESIGN SCIENCE RESEARCH AS AN APPROACH FOR ENGINEERING EDUCATION RESEARCH

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ABSTRACT

Design Science Research is a research approach that is widely used in information systems, IS, but also in other areas where the development of an artefact is parallel to the development of a theory or methodology for this development. In our research we have developed the model “the learning of a complex concept”, LCC, as a method to analyze learning outcomes, as well intended as experienced by students.

In this paper we will show how this model was developed, and how design science research was used to develop a methodology that may now be used in the iterative design and analysis of learning outcomes. LCC was developed while designing teaching sequences in a course in electrical engineering. The model was derived as a means to analyse videorecordings of students’ actions, during lab-sessions in an electric circuit course in the first year of an electrical engineering program.

The model has contributed to the understanding of learning but also to the design of learning materials, and design science research has improved the methodology. Can this become an especially appropriate methodology for analysis of CDIO-projects? What may be learned, and what is actually learned in a CDIO-project? How can “the learning of a complex concept” (LCC) be used in the iterative design process designing a CDIO-project?

KEYWORDS

Learning of a complex concept, design science research, engineering education research, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 10.

INTRODUCTION

In an attempt to study learning in engineering education, we video-recorded students’ actions in a lab course on electric circuit theory. Since the amount of data was very large (for the whole course ca 250 hours of videorecordings, and for this particular lab ca 40 hours) we tried to find a way of analyzing students’ difficulties by looking at the questions that were raised during the labs. We used the method *Practical Epistemologies* (Wickman, 2004), where the researcher looks for gaps in students’ conversations, when they encounter something that is new to them. We represented our findings graphically in a model, where the topics students were talking about were represented by circles (nodes) and switching to another topic by an arrow (link).

Often questions were raised at these points. This model was refined and used both for analysis of students' actions and to design new lab-instructions (Anna-Karin Carstensen, 2013; Anna-Karin Carstensen & Bernhard, 2007). However, modelling is an engineering endeavor often taken for granted, as is also design (Mitcham, 1994), and there was a need to turn this method into a methodology for engineering education research. Since in design science research “the design researcher arrives at an interpretation (understanding) of the phenomenon and the design of the artefact simultaneously” (Vaishnavi & Kuechler, 2008) it seemed fruitful to explore the derivation of the LCC-model by means of design science research. This exploration was presented at the Engineering Education Research Symposium 2015 in Dublin (A-K. Carstensen & Bernhard, 2015). Here we will summarize the exploration and show how the methodology may be used in analysis of learning outcomes in a CDIO project course.

DEVELOPING A METHODOLOGY

One of the strengths of design science research is the iterative process rendering the theory, since the same method is used for development and evaluation. The refinement of the designed artifact is aligned to the development of the theory. The LCC-model can be considered to be a design artifact, and the “evaluation of the artefact then provides information and a better understanding of the problem in order to improve both the quality of the product and the design process” (Hevner, March, Park, & Ram, 2004, p.78).

The methodology most often used in design science research in information technology is the method described by Takeda, Veerkamp, Tomiyama, and Yoshikawa (1990):

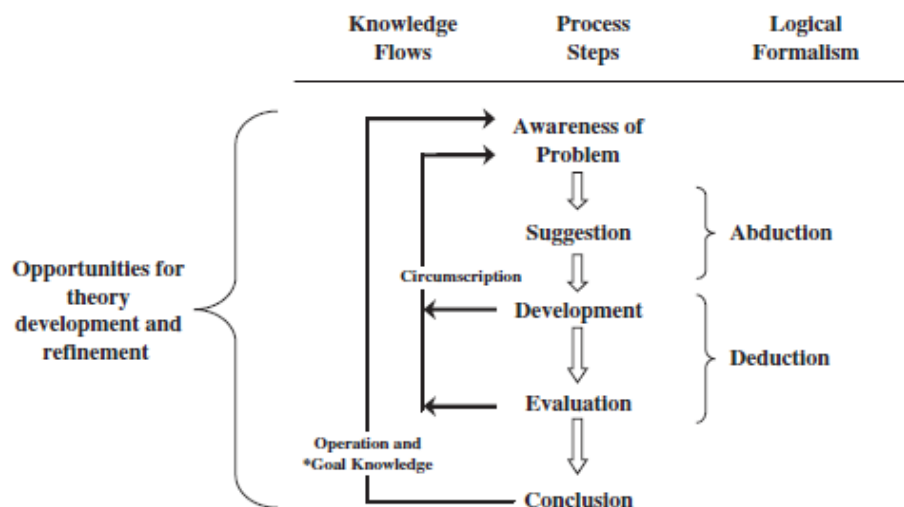


Figure 1: The design cycle originally proposed by Takeda et al. 1990 (as displayed by Kuechler & Vaishnavi, 2008, p. 493)

The iterative process gives opportunities to refine the artefacts, and models, but also for theory development (Kuechler & Vaishnavi, 2008). The theories that inform design science research belong to either of two categories, *descriptive* and *prescriptive*, where the descriptive, also called *kernel theories*, frequently have their origin within other disciplines, and the prescriptive, the *design theories*, are prescriptions of “how to do something”.

Typically the design cycle starts with the awareness of a problem (Figure 1), and an analysis of the normally wicked and complex problem. The first suggestions towards a “solution are abductively drawn from the existing knowledge or theory base for the problem area” (Vaishnavi & Kuechler, 2008), often theories from other disciplines, termed *kernel theories*. In our case we used analysis methods from pragmatism in the analysis of students’ actions (Wickman, 2004) and from phenomenology in the analysis of “the intended object of learning” (Marton & Tsui, 2004).

A suggestion is then made, in our case the LCC-model was designed, and used to design new teaching sequences. As well the model as the labs were then evaluated, and especially the model has been refined in subsequent design cycles. However the evaluation is not the last step since this is an iterative method, the circumscription is of uttermost value. When designing a car, the prototype is not the last step, there is always a new iteration of the car design starting the moment a prototype is ready to launch.

THE THREE DESIGN CYCLES FROM OUR METASTUDY

(Summary of the metastudy in A-K. Carstensen & Bernhard, 2015)

First design cycle

In the first design cycle we had video-recorded students’ actions in a lab course in electric circuit theory. One of the labs concerned “Transient Response”. We needed a way to analyze the problems students faced when dealing with this topic, in order to design a new lab-instruction. The amount of data is very large, and thus the need for a method to condense data is necessary. Our first attempt in this was to listen to the students’ discussions and look for the occasions students asked questions. We used the method of *Practical Epistemologies* (Wickman, 2004) where the researcher looks for gaps in students’ conversations, when they encounter something that is new to them. Analysis of the questions showed that the questions seemed to occur when students were changing topics to discuss. For example the students started to wire up the circuit, and the first questions concerned how to connect the leads for measuring. Thus we started to draw the questions as arrows, and the discussions on a topic as nodes, “islands”, which lead us to draw the two circles called “real circuit” and “measured graph”, and although we did not write any labels on the arrows, they represented the action where the students connected the circuit to the computer-interface, and started to measure (using a computer interface measurements directly render graphs). Now the next action expected was that the students should try to make the computer draw the calculated graph in the same diagram, by use of the mathematical expression of the time function. In the first course the students were not able to do this without help from the teachers, and thus they asked “Is this good enough for the report”, showing that they did not make the links between the topics but only talked about one concept at a time.

Thus we tried to analytically draw what nodes and actions we had expected the students to talk about, what in *the Theory of Variation* is termed the *intended object of learning* (Marton & Tsui, 2004) – and draw the nodes starting with the real circuit, onto the differential equation, further to the Laplace Transform in order to calculate the solution to the differential equation by searching the inverse transform, i.e. the time function. In this first course the arrows were not actions done by the students, rather they were the path of topics in a traditional teaching sequence or text book. The gap between the measured graph and the calculated graph – which was very clear in the video recordings, thus appeared as a gap between what was taught in theory classes and what was expected actions in the lab-sessions.

According to Tiberghien and co-workers (e.g. Vince & Tiberghien, 2002) who consider the learning divide be between the theory/model-world, and the object/event world (rather than between theory and practice) the most problematic steps for students to take are those

transcending the two worlds, and by studying the newly drawn model it was obvious that those passages were very small and very few.

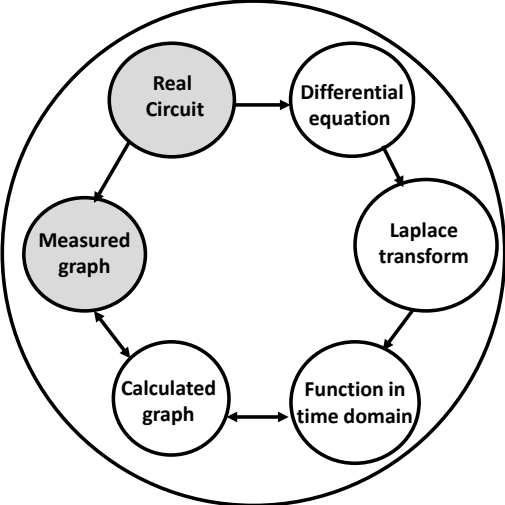


Figure 2: First Design Cycle – Intended object of learning

Our proposition thus became to try to find arrows across the circuit. One of those would be to draw an arrow from the Laplace transform, the transfer function, directly to the calculated graph, something that could be possible to make through simulations of various transfer functions in Matlab-Simulink.

Second Design Cycle

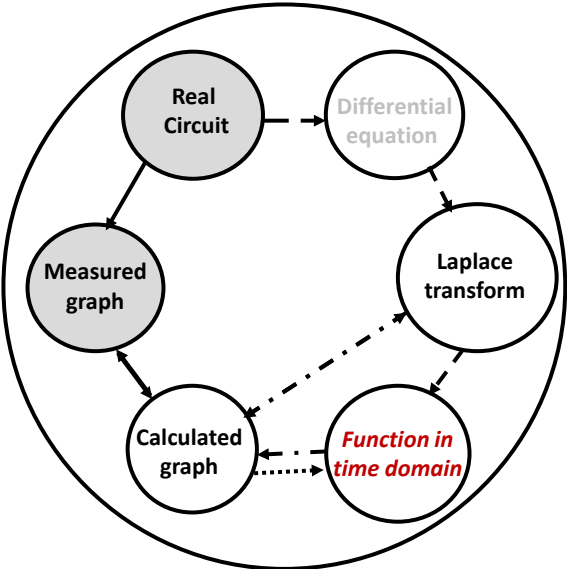


Figure 3: Second Design Cycle – Design of new teaching materials

In figure 3 the dashed arrows are showing the teaching sequence in the lectures, the dash-dotted arrows show the two tasks explicitly asked for in the new course, where problem solving sessions and labs were integrated. The students were now asked to analyze the correlation

between the calculated graph and the function in the time domain, the dotted line, in order to realize what parameters in the time-function that rendered differences in the calculated graph. Now the students worked in a totally different way than in the old course: Some students started to do the calculations, and some started to do the simulations, and the new video-recordings from the revised course rendered two different versions of the model:

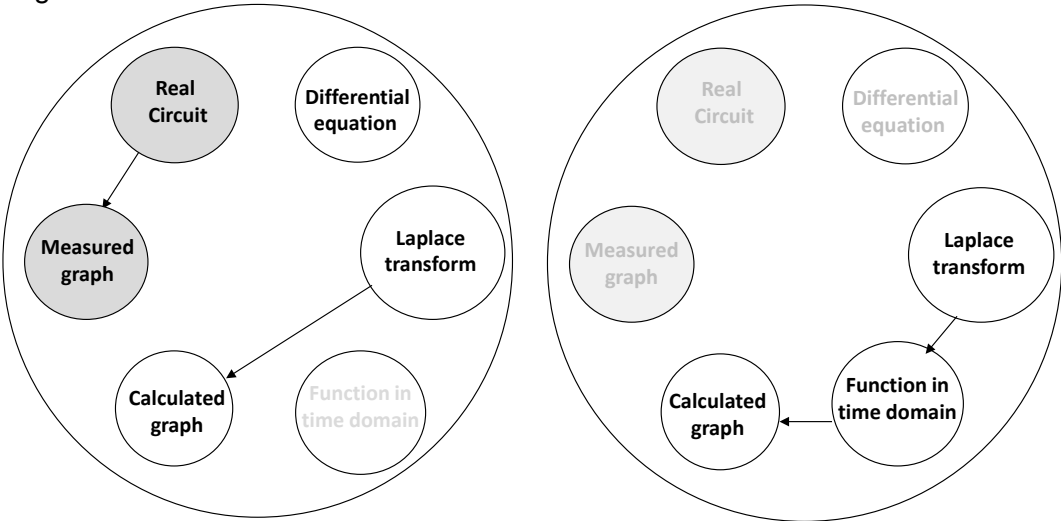


Figure 4: Two different students' paths due to different actions

The student who first measured a couple of graphs, then jumped to the simulation task without any connection to what he had measured, led to the left figure, and the student who started to do calculations made us draw the right figure. At the end of the lab both students had worked the whole lab through and made all the links in figure 5:

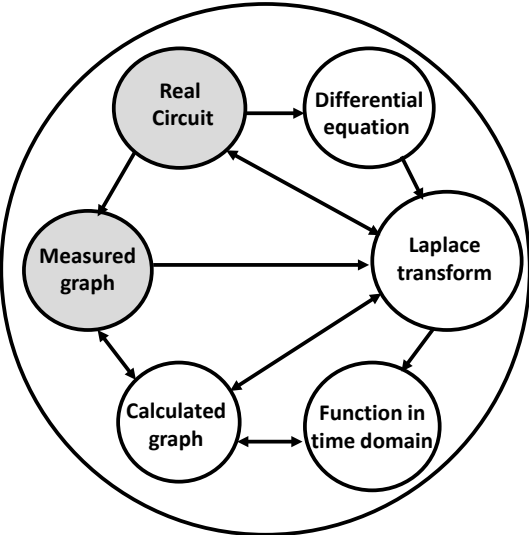


Figure 5: The students' paths at the end of the lab in the new course

In this new course not once was the question “Is this good enough for the report” asked, since now the students had made all the links that were necessary in order to understand the complex concept “transient response”.

Third Design Cycle

The two first design cycles were focusing on the analysis and design of the lab instructions. Now it was necessary to start the analysis of what knowledge this designed model could bring to the engineering education research community, the phase that Vaishnavi and Kuechler (2008) call “circumscription”. In Figure 6 we can see that two of the nodes have double labels. The first pair of labels were *Laplace transform* and *Function in time domain*. Of course the Transfer function is the Laplace transform of the differential equation, and thus a noun, but the Laplace transform is also the action that has to be taken in order to go from the differential equation to the transfer function. Similarly the Inverse transform is the action that transforms the transfer function into the function in the time domain, i.e. it is not a node but an arrow. The confusion here due to the word transform being as well a verb as a noun, highlighted that all nodes were nouns and all arrows verbs, as in other types of models such as concepts models or concept maps. However it also highlighted that the verbs, the actions were not just rote actions. It was necessary for the students to have both nodes in focal awareness while making the link between them. Thus the links, the arrows are not just there to learn but are actions students need to do in order to make links between concepts, i.e. to learn complex concepts is to do something that connects the islands. Here the analysis of the designed model thus leads to a new learning theory, that to learn complex concepts is to *make links*.

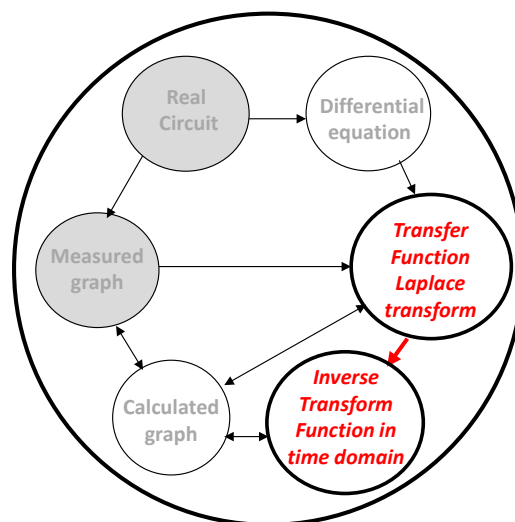


Figure 6: The model “the learning of a complex concept”

In the third cycle also the other links were explored (Anna-Karin Carstensen & Bernhard, 2013), but are omitted in this presentation.

A METHODOLOGY FOR FURTHER RESEARCH - FINDINGS FROM THE DESIGN SCIENCE RESEARCH EXPLORATION

The above presented exploration may be summarised in the figure below:

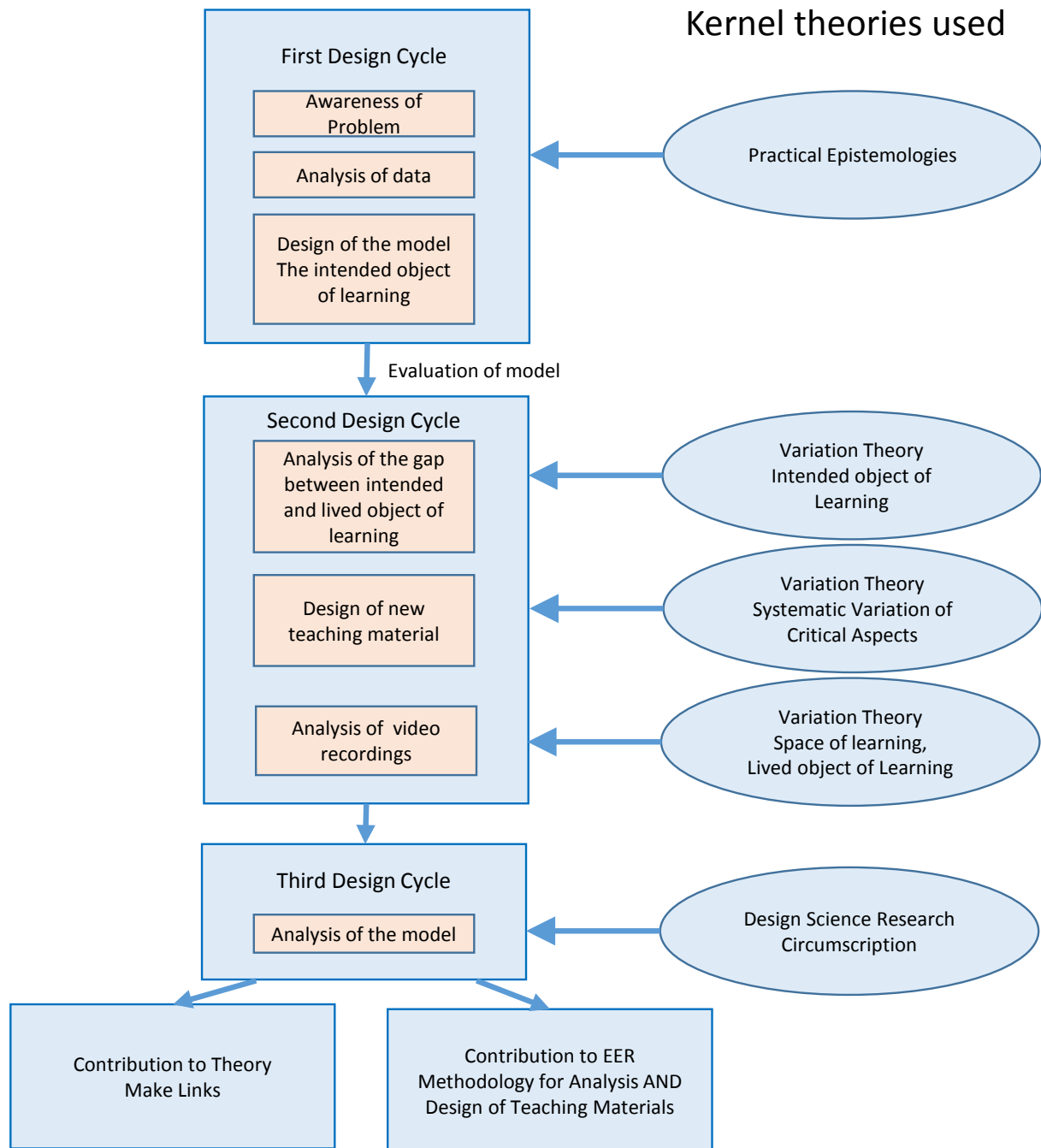


Figure 7: The Design science research process and the resulting contributions to the EER-field adopted from Takeda et al. 1990, with reference to referenced kernel theories from education (A-K. Carstensen & Bernhard, 2015)

EXPLORING LEARNING OUTCOMES IN A CDIO-PROJECT COURSE – A WORK IN PROGRESS

Previous research on learning outcomes in CDIO-project courses have mainly discussed collaborative learning of design processes, and learning to design, but not often what may be learned *through* working in design projects, especially how disciplinary knowledge may be learned through CDIO-projects (see e.g. Bernhard, Edström & Kolmos in this conference). By using the design science approach in figure 6, it seems possible to analyze the learning by analytically separating process knowledge, disciplinary knowledge and collaboration skills.

At our university in Jönköping we offer several opportunities for CDIO-projects. One is through an internship course, NFK, which is a 7 weeks internship, where one of the topics students' report on is to analyze their learning at the internship workplace to the learning in their courses, e.g. which course learning outcomes did you use at the workplace?, and what learning outcomes do you view as inappropriate. In an ongoing study we are analyzing the learning outcomes of this course. We have collected reports from the students, we are in the process of interviewing the students after one semester of courses after the internship. Our preliminary findings show that there is an astonishing shift in the students view of their own knowledge, e.g. one student writes in his report that "I thought I got the worst project of all students", but later he compares the learning outcomes in the course plan with what he actually learned and claims "I never thought I would have enough knowledge, but now I have both learned more and been able to use the knowledge I gained in the previous courses." We have seen the attitude towards studies changed, and also seen the group dynamics change remarkably – one of the most dominant students in the group before the internship course is no longer considered the leader of the group due to his attitudes towards studying. This remark has to be further explored in the interviews, but is still worth mentioning in these preliminary findings. Two previously rather weak students, gained self-confidence from their project and also the company was very satisfied with their accomplishments.

USING THE MODELLING APPROACH TO INVESTIGATE THE LEARNING IN THE INTERNSHIP-COURSE

In order to make these findings analyzable we have started to use the approach in figure 6 to model the learning in this internship course, separating the interpersonal skills, disciplinary knowledge learned, impact on future courses, and so forth and try to see what links between these analytical categories students make. We will use this model to redesign the curriculum and reanalyze the learning outcomes regarding as well explicit learning outcomes as in what way we may facilitate students' learning paths.

First design cycle

Starting with a first cycle – What learning outcomes do the students report on spontaneously in their reports? We have here started to analyze the reports handed in by students in computer science majoring in embedded systems. In the reports the students reflect on their learning in relation to courses they have taken before the internship course, but also on their own expectations.

So far the students have taken around 14 courses of different length and content. The courses that are mentioned as relevant to the internship are Introduction to electronics, Human-machine and electrical interfaces, Microcontrollers, and Operating systems for embedded computers. Some students mention Digital electronics with VHDL and Research methods and communication. Only one student mentions introduction to programming and none of them

mention following programming courses. This raises more questions than can be answered without making interviews with the students. Have the students already chosen to mention the major-specific courses? Or are these the courses they felt less on the track of their expectations? Both questions may have their answers in students' responses to course evaluations. During the electronics courses students have commented on the fact that reading datasheets is a difficult task that they would rather skip but in the reports this is what they mention as one of the most important learning outcomes from these courses. Also the comments regarding choice of programming language in the courses are made in the reports: "I have noticed that this language [C-programming] actually is used in practice. I am glad that I got the opportunity to learn this thoroughly before I started my internship." Another student concludes with the remark: "When out there, you also get a sense of how broad this education really is"

As in figure 6 the second cycle will start with the discrepancies between intended and lived objects of learning: How do the expectations of the studies affect the learning outcomes? And how may curriculum development, including the internship course, facilitate for students becoming engineers. Since the reports show that expectations, fears and self-esteem are important factors that students bring forward in their reports, this will also be modelled into the learning model. These results are in line with previous results on motivation in engineering education (Edström, Törnevik, Engström, & Wiklund, 2003), however, the students' reports also show that the motivation may change due to the internship course, and thus this issue is of uttermost importance in making the curriculum design.

As a point of departure, the model from figure 9.1 (Crawley, Malmqvist, Östlund, & Edström, 2014, p. 214) where the links between elements of the curriculum, CDIO standards and evaluation of learning are modelled.

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BIOGRAPHICAL INFORMATION

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