Three Step Development Model used for Active Learning in Electrical Engineering

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INTRODUCTION

Over the last decade more and more attention has been put into changing the engineering education from traditional large class–room teaching towards bringing more practical aspects into the teaching. This trend has also been formulated in the CDIO-concept (Conceive-Design-Implement-Operate) [1] for teaching. Active learning is one of the main ideas behind CDIO which is best achieved by letting the students work with practical assignments. This activates the students and helps them to make their own observations and thereby their learning is based on own experience rather than knowledge learned through traditional lecturing. Active learning can be described using Kolb's learning cycle [2] which also results in deeper learning. However, Kolb's learning cycle describes how learning is achieved and it is difficult to use actively during the teaching. Thus, tools are needed to help the students to gain knowledge through active learning. In this paper we describe how the students are guided through the steps in Kolb's learning cycle by the use of a 3-step development model combined with a 4-phase problem solving methodology and coaching.

In section 1 the course setup used for the teaching is shortly presented to put the discussions on teaching into perspective. In section 2 the 3-step development model is presented. In section 3 we describe how Kolb's learning cycle relates to the 3-step development model. Section 4 presents the problem solving methodology and we describe how this – combined with coaching – guides the students through Kolb's learning cycle. Finally, some discussion and course evaluations are presented.

1 THE COURSE SETUP

The 3-step development model is used in the teaching of courses in integrated analog electronics at the Technical University of Denmark (DTU). Integrated analog electronic circuit design is taught in 3 scheduled courses and a final special course (individual course) as shown in Fig. 1. The first course (31631, [3]) is a traditional lecture course teaching the fundamental theory of circuit design. In the second course (31632, [4]) the students are given their first synthesis assignment combined with lectures. The third course (31633, [5]) is a 3 week course where the students for 3 weeks work full-time on a synthesis assignment. Integrated circuit design has some special challenges in the sense that experimental fabrication has to be outsourced. The time for fabrication is 3-4 months and it is quite expensive (10,000-20,000 EUR). Thus, the fourth course is only conducted (on an individual basis) for students who commit themselves to perform measurements on the designed circuit.

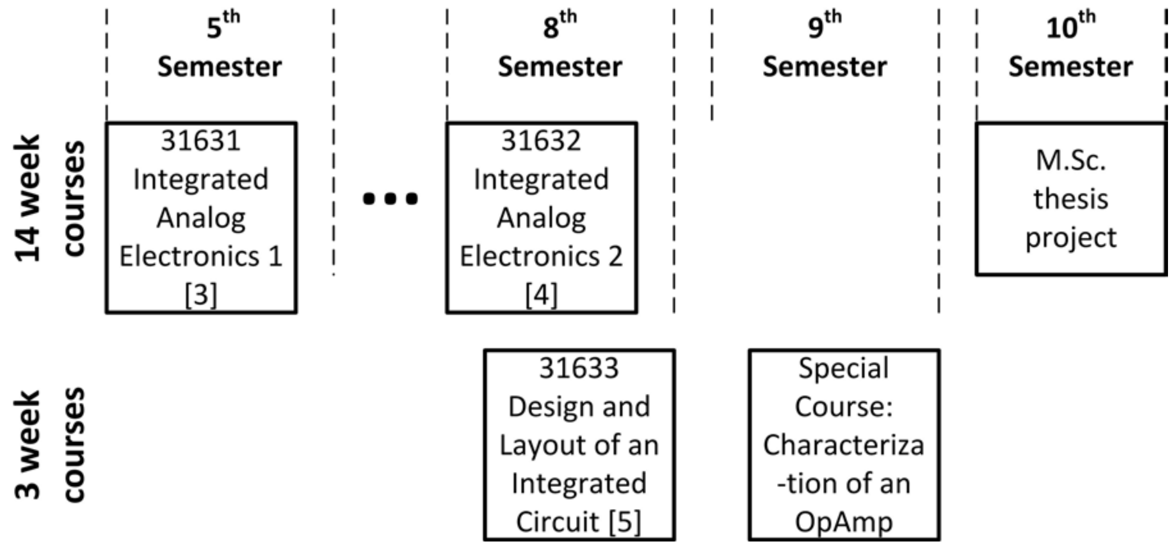

Fig 1. Course flow in integrated analog electronics at DTU.

The courses are designed so that the students start with the theory, then continue with synthesis and simulation tools and finally perform measurements on their circuit. This also follows the 3-step development model introduced in the next section. The courses have been designed using constructive alignment [5]. As the two middle courses focus on synthesis of electronics, not only one but many solutions exist to the problems which go well in hand with active learning. Consequently, many higher level learning objectives (SOLO (Structure of Observed Learning Outcomes) and Bloom's taxonomy [6], [7]) are required in these courses.

2 THREE-STEP DEVELOPMENT MODEL

In electrical engineering, development can be divided into three phases as illustrated in Fig. 2. This can probably be adapted to most engineering disciplines.

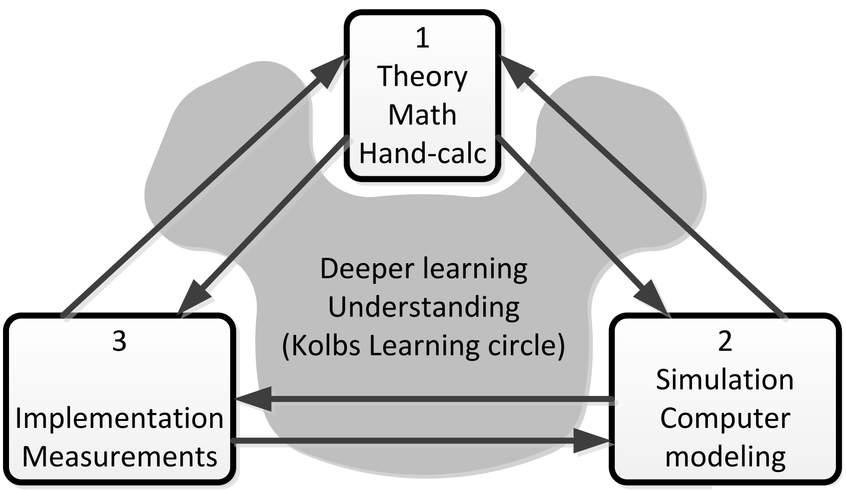

Fig 2. The 3-step development model

The first phase mainly comprises the theory and mathematical modelling of about electronics. Going from the theory to actual circuit implementation requires that the student can synthesize a circuit from a specification. In electronics this is done using hand calculations (theory) and specialized computer simulation tools. The latter is needed as the basic components used for the circuit design are very complex meaning that hand calculation can only provide simplified and inaccurate results compared to the accurate modelling provided by the simulations. Many software tools exist in the market for this and it is an essential part of the skills of an engineer to be able to handle one or more of these tools. The last phase is the physical implementation and verification of the circuit. For engineers to be skilled in electronics they need to be able to operate smoothly between the different phases in order to successfully synthesize electronics. Note, that the teaching in the courses is aligned with the three phases in the 3-step development model.

This development model with the three phases is presented to the students from the beginning of the second course. Here the focus is merely on the first two phases as the third phase is only applicable in the fourth course where a circuit has been experimentally fabricated. At the same time some effort is devoted to explaining to the students that engineering work in general deals with synthesis of circuits from a specification rather than analysis of a given task. This is what engineers do. They develop new circuits. They do not just analyse old ones. Thus, an engineer must be able to make observation in the three phases and make decisions based on these to progress. It is only when the relation between the three phases is well understood that deeper learning is achieved.

3 KOLB'S LEARNING CYCLE

Obviously, the purpose of the teaching is for the students to achieve deeper learning by going through the phases of Kolb's learning cycle [2], see Fig. 3. When the students are working on their circuit design they will of course encounter problems. The aim is then to encourage the students to reflect on these and eventually – based on the fundamental theory that they have learned – to come up with one or more possible solutions. They will then verify these, e.g. either in the simulation tool or by verification on a physical implementation.

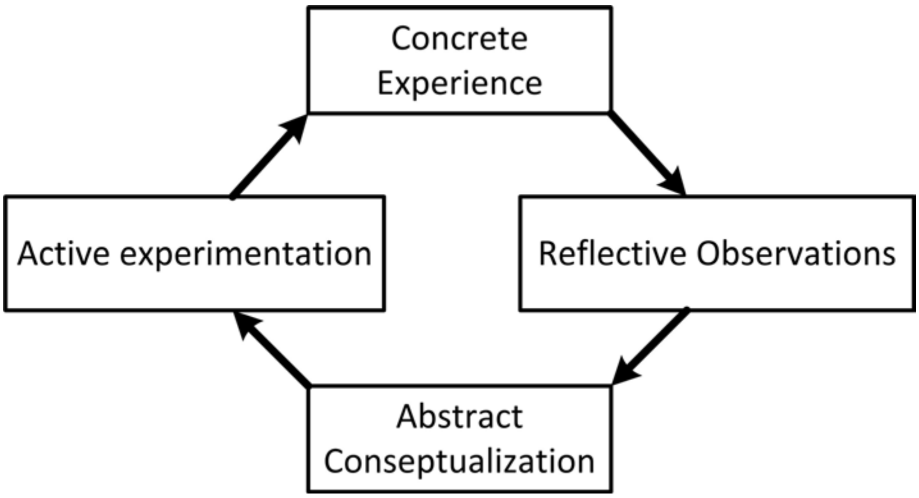

Fig 3. Kolb's learning cycle

However, Kolb's learning cycle is quite abstract for the students and thus a problem solving methodology is used which systematically forces the students to go through the 4 phases in Kolb's learning cycle.

4 PROBLEM SOLVING METHODLOGY

As problem solving is one of the most fundamental generic engineering competences it has a substantial focus in the courses. Also, it is through problem solving that the students go through the phases of Kolb's learning cycle, hopefully leading to deeper learning for the individual student. Therefore, the students are presented to the four step problem solving methodology shown in Fig. 2. This model is a simplified model of a 7-step model used by the US military [9].

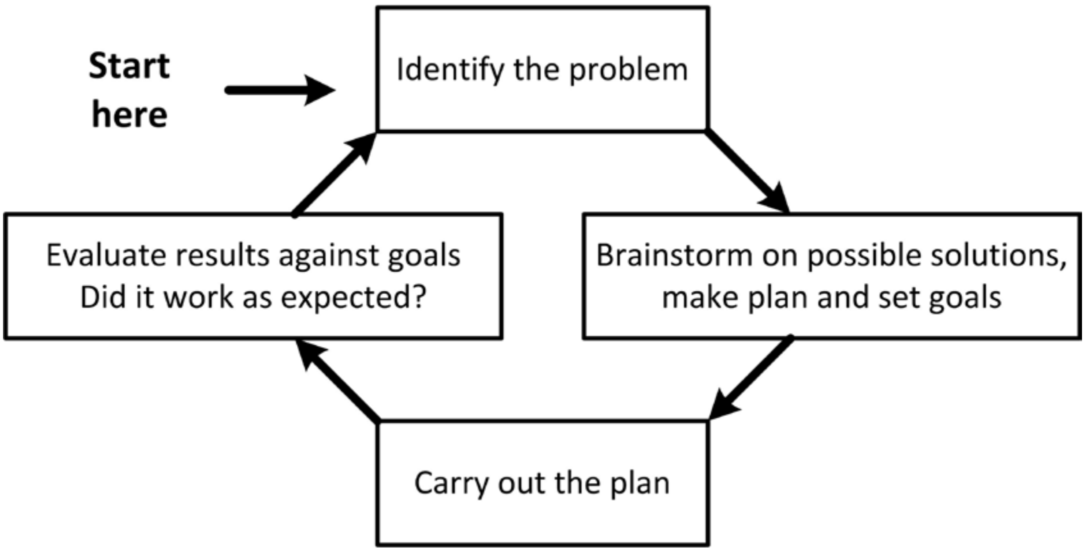

Fig 4. The problem solving methodology

This problem solving methodology was introduced in the teaching as it was observed that many students often just pursue the first possible solution that comes to their mind when observing a problem. This often resulted in the students ending up in a trial-and-error mode with little or no learning.

The problem solving methodology of course starts by the students identifying a problem in their design, e.g. a specification parameter which cannot be met. After this, a brainstorming session is initiated. It does not have to be a formal meeting, just a discussion at the desk will do. This can either be the students on their own or the teacher can participate. Actually, this is where the majority of the teaching effort lies. The brainstorming session starts with the students explaining the problem, and after this the teacher mainly asks the students what could be the root course of the problem (coaching technique is used). This forces the students to brainstorm on possible explanations to the observed problem before they decide to investigate one of the possible solutions to the problem.

The four steps in the problem solving methodology systematically take the students through the four steps of Kolb's learning cycle. However, it is much easier to explain the problem solving methodology to the students than it is to explain Kolb's learning cycle. Thus, the problem solving methodology is the means and Kolb's learning cycle is the goal of the teaching.

5 DISCUSSION

In the previous sections the 3-step development model and the problem solving methodology have been presented and we have explained how these are used in the teaching. In this section we discuss how the model is used for assessment and self-assessment. Also, limitations to the use of the teaching technique are discussed. Finally, an example from one of the courses is given.

5.1 The model and assessment

When the teacher participates in the brainstorming session it is apparent that this is a good way of assessing the knowledge of the students. By listening to the students arguing for possible solutions the teacher can evaluate how the students' level of learning is and how well they can link their knowledge and experience from the three phases in the 3-step development model. This can of course be applied in the grading of the students but more importantly it can be used to identify topics which need to be addressed with additional and supporting teaching. Actually, the teacher continuously provides personal feedback to the students, both in terms of their technical and human skills using a verbal feedback technique [6].

5.2 The model and self-assessment

As the students learn they will progressively be better at combining the observations and knowledge gained in the three different phases in the development model. This also enables them to self-assess their work. For example, if they have some observations in the third phase (measurements/verification) they will utilize the results from the two other phases to judge the validity of these observations. If the observations do not meet the expected results obtained from the two other phases the students have identified a problem and initiate a brainstorming session according to Fig. 2. It is explained to the students that engineers are expected to be able to do so on their own and thus this kind of self-assessment is strongly encouraged in the courses.

5.3 Limitations to the use of the model

As the present model and methodology requires quite a lot of contact hours between the teacher and the students on an individual basis the technique is best suited for small to medium sized classes. Also, the model requires that the students have some knowledge in at least one of the phases in Fig. 2, implying that this technique is best suited in the last half of the engineering curriculum.

5.4 An example

Two students were working on the development of a circuit and encountered a problem. They asked the teacher for a meeting and a brainstorming session was set up. During this session (lasted for approximately 15 minutes) the students were very determined on a specific solution to their problem, a solution that the teacher knew would not work. Therefore, the teacher kept asking for other possible solutions to the problem in an attempt to shift the focus of the students. However, the students decided to investigate the first solution they came up with and made a plan for their further work. After two days (out of a 15-days curse) the students returned and explained that their suggested solution did not work and asked if the teacher knew this. The short answer was "Yes" which made the students quite upset. Consequently, the teacher had a discussion with the students about doing development in the 3-step development model, about using problem solving as a tool and about how much is learned by doing mistakes if the mistakes can be put into perspective in the 3-step development model. After this discussion the students realized that they learned a lot from this "de-tour" which turned their view on the situation. They then decided for a new potential solution and made a plan for their investigations. This turned out to work.

6 COURSE EVALUATION

The third course in analog integrated electronics (31633, [5]) has just been established 2½ years ago. It was created to enable the students to make their own integrated circuit. At the same time a considerable emphasis was put on improving the generic engineering competences of the student and of course also on their circuit design skills [10]. The described 3-step development model and problem solving methodology is extensively used in this course.

The course has been taught twice and each time the course has been evaluated using the Course Experience Questionnaire (CEQ) [11], [12]. Through 22 questions the students evaluated the course in the five categories listed in Table 1 where "1" and "5" are the lowest and highest score, respectively. In addition to the questions the students are also asked to state what they find to be good and what could be done to improve the course.

The results of the CEQ are based on answers from 15 students who completed the course and the average scores are shown in *Table 1*. Three students dropped out of the courses after less than one week as it turned out that they did not fulfil the pre-requisite for the course and thus did not participate in the course evaluation. The students were organized in groups of two where each group was responsible for a complete design task.

Table 1. CEQ average scores based on the feedback of the 15 students completing the course 31633

Category	**Average (1 -5)**
Good teaching (GT)	4.24
Clear Goals and Standards (CG)	3.91
Appropriate Workload (AW)	3.56
Generic Skills (GS)	4.04
Motivation (M)	4.61

The results in all categories are good. The workload seems appropriate. It is not surprising that the second lowest average score is the "Clear Goals and Standards" as the students are rarely given straight answers to their questions/problems but rather coached using the problem solving methodology to find their own solution to the problems. Even though this technique is used the score is still quite high. More importantly, the average score of 4.61 in "Motivations" is very high, clearly showing that the students appreciate the way to learn. Also, they feel that their generic engineering competences are improved.

Besides the numeric scoring many of the comments from the students also state that they highly appreciate the problem solving methodology and the fact that the course emulates a real life scenario (the course emulates a project in a company with the teacher being the CEO [6], [10].

7 SUMMARY AND ACKNOWLEDGMENTS

In this paper a 3-step development model applied for teaching in electrical engineering is presented. The 3-step model is used to describe to the students the three different phases generally encountered during integrated circuit design. It is explained how the students – when working with synthesis assignments – make observations and use the knowledge gained to go through a learning process which can be described by Kolb's learning cycle. In order to ensure that the students achieve deeper learning via Kolb's learning cycle a problem solving methodology is introduced to the students. This problem solving methodology has four phases mapping to the four phases in Kolb's learning cycle and it is designed to ensure that the students go through the four phases in Kolb's learning cycle.

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