DEVELOPING AND IMPLEMENTING A PROGRAM INTERFACING PROJECT COURSE IN ELECTRICAL ENGINEERING

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ABSTRACT

In this paper, we describe the ideas behind a second-year Design-Build course in Electrical Engineering. Electrical Engineering is a theoretical subject, and in such it is difficult to maintain the theoretical level in project courses introduced too early in the program, especially when core subjects like electromagnetic field theory are involved. This issue is addressed and we also describe our approach for the assessment of the students. We also discuss the different goals that were set up prior to the course from a program perspective; how we reasoned when designing the course, the assessment structure, and the output once the course was implemented.

KEYWORDS

Project course, Design-Build, Electrical Engineering

INTRODUCTION

At KTH, one of the originators of the CDIO approach, there has recently been a general requirement to strengthen CDIO activities on all five-year programs. The focus was less on Conceive, Design, Implement and Operate (CDIO) activities and Curriculum Design [1], instead the focus were on integrating general engineering skills such as teamwork, written communication, oral presentation, project management, peer-review and innovation into the programme courses. For these areas, KTH provided support functions.

One of KTH programmes is the five-year Electrical Engineering (EE) program. It is a traditional, course-oriented program with a solid theoretical foundation. It also has many of the general engineering skills already built in [2]. However, Design-Build activities are too few, and there is a need for activities tying the different core courses together. While we believe that the general applicability of the content taught in the courses is a strength of the programme, we have seen that students tend to be drawn towards programmes with application-specific names when they cannot visualize the work role of an EE engineer. In fact, there is a general uncertainty in society of what an Electrical Engineer really does. Given that, and the emerging innovation-based structure of industry, the programme would clearly benefit from more design-build activities.

Another recent change at KTH is the evolvement from five-year standalone programmes into five-year programmes with a 3+2 bachelor-master structure. It is formally implemented, but there are still many challenges to address, like e.g. the implementation of CDIO activities and how to profile the bachelor level part of the programme. Since the program was previously a five-year standalone programme, many of the profiling courses were given during the 4th and 5th years. With the change to the bachelor + master structure, we find it important to strengthen the electrical engineering profile already at the bachelor's level. There is however a challenge to maintain the theoretical level and still be able to offer a broad program that prepares the students for the variety of masters programs that are offered to the students during study years 4 and 5.

Enhancing the programs profile is perhaps the most important retention activity we can do for the new generation of students. The students constantly evaluate if their choice of education was the right one [3]. They need to know on much earlier stage where their investment in education will take them. Most often they lack hands-on as well as industrial experience and find many of the theoretical subjects difficult to grasp. This is also related to a lack of understanding of the role of the theoretically heavy subjects such as math and field theory in the applied subjects later in the programme. Thus, an important conclusion is that if we bring together and apply the content from some of the traditionally taught courses of the programme through a Design-Build course in which the students can apply their EE knowledge in a real engineering task, we could strengthen the EE-profile and also help the students (already when doing their bachelor) visualize the work of an electrical engineer. The introduction of a project course with the right kind of project, would not only strengthen the student's general engineering skills, but also bring to life and thereby strengthen the theoretical content of the other courses connected to the project course [4]. The main courses targeted in our case were: Electromagnetic Field Theory, Wave Propagation and Antennas, Signals and Systems part I & II, and Electrical Measurements.

However, it is difficult to create a real and valuable design and build experience by applying relevant theory in a project course that appears at an early stage in the EE program. This is especially true when highly theoretical core subjects like electromagnetic field theory and signal analysis are involved.

To address some of these issues, a group of teachers responsible for courses at the bachelor level were assigned the task to develop a new project course – a Design-Build course. As a starting point for the discussion, the following list of suggested programme and learning outcome objectives were given to the group.

- Enhance the profile in Electrical engineering by strengthening core courses
- Apply knowledge from the core courses. Enhanced knowledge in basic modelling techniques, like the ability to make estimations and simplifications that reduce the problem to an elementary calculable complexity.
- Be able to formulate, evaluate, and choose a technical solution to a given problem.
- Be able to identify deficient areas in one's knowledge and awareness of the personal responsibility for one's own development of knowledge.
- Training in the ability to explain the theories and technical systems treated in the course for a person who is not an engineer.
- Further training in teamwork.

- Training in giving and receiving feedback in a constructive way.

Next we describe how the course was designed from these learning outcomes. The paper is structured as follows. We begin by describing how the course was designed, what kind of decisions that were made and which alternatives were evaluated. We then continue with how the course was implemented, followed by the outcome of the first round. We analyse the results and discuss areas for improving the course design. Finally, we conclude with our experiences of placing this kind of project course in the second year of the programme.

COURSE DESIGN

Since most assignments in the programme are clearly specified or catered for success, we wanted this assignment to be very open. We decided that the students should be introduced to the requirements, work with them for a while, present a prototype or model, get feedback and then develop their solution.

Although we saw the benefits of giving the whole class a system development task, with different student teams being responsible for different parts, to promote understanding of task interfaces, it was decided at a fairly early stage to let all students solve the same task. The reason was partly because it would have been difficult to find a sufficient number of suitable sub-tasks and partly because it treats all students equally in terms of workload and grading. It was also decided early that students should be randomly assigned into teams of 3 to 4 by the teachers at the start of the course [5]. Assigning the students was a logical continuation since the students were allowed to create their own teams in the first year project course.

With all teams having the same task we had to consider the information flow between the teams. We wanted an open information exchange but we did not want the teams to copy from each other but rather be inspired by each other. For this reason we introduced an element of competition between the teams, cf. the section Assessment.

For the supervision we considered two main alternatives. Either we could give the teams a list of teachers and their special competences and allow the students to book a time when they needed help, or we could create a reference group of teachers and ask the students to present their progress at regular meetings with the reference group. To give the teachers' good and common understanding of the pedagogical process we decided to go for the later alternative with a teacher reference group. Once a week, the students have the opportunity to book a time for supervision by the reference group, and there are also a few compulsory supervision meetings. In a few years when we have gained some experience with the course, this could be reconsidered.

Based on previous positive experience with a multiple-submission assessment such a system was adopted, cf. the section Assessment.

Project task

A significant development time was spent on finding a task fulfilling the following requirements.

- The students should be able to build the device more or less from scratch.
- The design should require theoretical knowledge in electromagnetics, including circuit theory, as well as signal processing and preferably also from other courses that the students have passed so far, e.g. classical mechanics.
- The students should be able to make and present an analytical model to give some guidance for the main parts of the design.
- It should be possible to measure the performance of the final prototype and relate the results to the design.
- The full workload, including project planning, modelling, implementation, measurements and reporting should not exceed 120 hours per student (4.5 ECTS credits).

One idea that was investigated in detail was the wire recorder – a predecessor of tape recorders, where the signal was stored by magnetizing a thin steel wire. We found a kit for building a prototype of such a wire recorder [6, 7, 8], but it did not produce sufficient sound quality to be a convincing example, even though a commercial recording head was used. Since we furthermore wanted the students to design and fabricate their own coils based on the analysis, the idea was abandoned. Among other ideas discussed were metal detectors, a field measuring device, RFID and simple radio communication. The project task that was eventually chosen to be implemented for the first run was that student teams should build their own loudspeakers.

The only prefabricated part that was allowed was the permanent magnet assembly, which could be taken from an existing loudspeaker. All other parts should be designed and fabricated by the students. A budget was also defined not exceeding the equivalent of 50 USD per person, thus about 200 USD per student team. Since this budget corresponds to the typical cost for the reading material in a normal course, we chose to let the students pay the material themselves.

A theoretical modelling of a loudspeaker involves an electrical part, a mechanical part – the membrane, which could be described using the concept of acoustic impedance – and the moving coil, connecting the two. The combined system can be described by a total transfer function. Design parameters that can be determined from such an analysis include dimensioning the coil and the membrane and relating these to the input impedance and frequency band.

Once the prototype has been built, the students should make measurements to judge how well their design fulfilled their design specifications and theoretically predicted performance. We also try to illustrate the benefits of digital signal processing, by asking the students to design an equalizing filter that compensates for the frequency response of the loudspeakers.

Implementation of the course

For practical reasons, it was desirable that the course extended over the full second year. This also has the added advantage that it gives time to reflect and digest. We wanted the activities to be fairly evenly distributed over the fall and spring semesters, so a natural division was to let the students do the planning, analysis and design during the fall term and the building and evaluation during the spring term. A complication was that several of the prerequisite courses are offered during the second study year, i.e., in parallel with the project course, cf. table 1.

We deliberately did not specify the project task in too large detail, but let the students themselves define more specific design goals, such as bandwidth, sound power and as well as budget within the constraint given. Such planning activity is not only intended to train project planning but also to trigger the students to start thinking about the technical details at an early stage.

In an attempt to train different forms of presentation, we decided to have an oral presentation of the theoretic modelling and design in the fall, but do the final reporting in the spring in the form of a written technical report. The oral presentation was organized on a single day with the different student teams attending each other's presentations, thereby providing a possibility for questions and comments both from other teams and from the teachers.

Table 1:
Timeline of the project course and related technical courses.

Year	Quarter	Project course activity	Theoretic courses & relevant concepts
1			Electrical Circuits • jω • Impedance Electro Project I • Basic project management & technical writing
2	1	Planning	Electromagnetic Field Theory • Electromagnetic induction, EMF Mechanics • Newton's 2nd law
2	2	Theoretic design Presentation	Signals & Systems I • Laplace, Fourier • Transfer function
2	3	Implementation Demonstration	Physic • Wave physics, acoustic impedance
2	4	Measurement Digital pre-processing Written reporting	Signals & Systems II • System properties • (Digital) filtering
	Year 3: Q1–Q2		Measurement technology

At KTH, the academic year is divided into four quarters (two per semester, Q1-Q4, see Table 1). The course thus begins a few weeks into the 1th quarter with an introductory seminar that provides practical information related to the course; presentation of the technical problems that the students will work on – designing and building a loudspeaker; an overview about working and thinking in terms of models when applying theory to practical problems. During this quarter, the students take their first course in electromagnetic theory, which provides some of the theory to be used during the second quarter while designing the speaker. Towards the end of quarter 1, the project teams submit preliminary work plans [9], for which the teachers give feedback. After some time to address the feedback, the project teams submit their work plans, which are graded by the teachers.

During the 2nd quarter, the students spend a substantial amount of time on modelling, analysing and designing their loudspeakers. It is however obvious that the students do not have the full theoretical background even in the 2nd quarter and need to search for some additional information, especially related to the concept of acoustic impedance.

The design parameters are to be simple enough so that the students can manufacture all of the parts except the magnet assembly themselves. Towards the end of quarter 2, the project teams present their designs to the class and teachers; and the presentations are graded. Once the design is approved, the students are allowed into a lab to start building their loudspeaker.

During the 3rd quarter, the project teams build their loudspeakers and evaluate their designs. The activity mainly takes place in the student workshop. At the end of the period there is an exhibition arranged, at which the teams demonstrate the performances of their designs and give a poster presentation. The performances and posters are graded.

After the speakers are built and presented, the task during the final 4th quarter is to improve the sound quality of the loudspeaker without changing the construction. The only possible method is by invoking digital filtering, which is a part of the Signal & Systems course. After this improvement of their loudspeakers, the teams work on their project reports; preliminary reports are submitted for peer reviews that are performed individually. Using the feedback from the peer reviews, the reports are finalized and submitted for grading.

Assessment

The assessment of the student is based on five different submissions/presentations (Project plan, Construction and calculation, Exhibition/Demonstration, Technical report, Peer-Review). The grading is a combination of individual and group assessments, thus the students will end up with individual grades. It is based on a structure we have used for many years at the program [2, 10]. The teacher reference group has the responsibility of the assessment process, but at some submissions other teachers are invited to participate as well as are the students (selecting for instance the best speaker at a fair where the speakers are demonstrated).

For each submission, there are criteria for plus and minus credits. For instance, submission 1, i.e., the work plan, has the following criteria.

- +1, Preliminary work plan submitted in time before its deadline (otherwise no feedback from teachers).
- +3 The work plan (final version) complies with the requirements and is understandable.
- +1 The plan is judged to be supportive for the team when carrying out the project work.
- +1 The plan is easy to grasp and is presented in a well-organized way.
- –2 The plan is submitted after the deadline.

Similar structures are used for all five submissions. In the exhibition, one additional credit was also given for the “best loudspeaker” as voted by the teacher and student groups respectively. The final grade is then based on the sum of credits for each student.

OUTCOME

At the time of writing, the course is still running, but most of the assessment submissions have taken place and there has been one course evaluation meting with student representatives and teachers as well as a partial course evaluation enquiry.

The students understood more or less what was required of them regarding the task, but they found the project plan of limited value in their work, because some parts of the task took much more time than they had estimated.

They were generally able to use the knowledge from the courses in electrical circuits and electromagnetic field theory, but felt that the mechanics course had not provided them with enough of tools for the mechanical design. When we write this, the signals and systems course has not yet been applied in the project.

A somewhat discouraging view from several students was that the theory and modelling part of the project did not really help them to make a better loudspeaker. The practical constraints and application of guidelines from literature reduced the design freedom too much. The exhibition event when the students were to demonstrate the loudspeakers was also criticised by the students. Apparently it was a very noisy event.

The student felt that the course is overall “medium” (average 3 on a scale from 5 (very good) to 0 (very bad). They appreciated the goals presented from the start, but felt that the information given was too vague and that the course took to much time related to the 4.5 ECTS credits it gives.

The students were also asked how much time they had spent on theory/modelling and actual building. The average was around 50 h on theory/modelling and 70 h on building. The signals and systems task and the report writing is not yet completed at the time of writing, but can perhaps be assumed to correspond to another 30 h, giving a projected time of 150 h. With the course design goal of 120 h of work, the subjective experience of too much work agrees with the reported time usage.

The presented grading scale was by many students considered unfair, because of the voting by teachers and students for best loudspeakers. This feeling was reinforced by the fact that only those with very good results in terms of bonus credits could get an A grade.

From the teacher’s perspective, we saw that the students were strongly engaged in the project. We also saw that the modelling and the design were a bit separated from each other. In fact the modelling was quite difficult for the students and they were in many cases happy to achieve some kind of model that could be reported. All teams made classical electrodynamic cone-type loudspeakers even though there are other possibilities.

We also note that the possibility for the students to book supervision meetings with the reference group was very little used, although we felt that this would have helped the students.

One important side effect the course has had from a program perspective is that it ties the faculty together, since a group of core teachers active at the bachelor's level both designed the project course and formed teacher reference group, which supervised and assessed the students. Situations like this, where teachers meet and together help the students creates awareness and sets in motion a discussion of what should be dealt with by teachers of other courses.

ANALYSIS AND SUGGESTED IMPROVEMENTS

A preliminary analysis suggests some changes for next round of the course.

The fact that the student did not feel that the time plan supported their work was perhaps partly because of the difficulties in estimating the time for various parts of the work. The feeling of not seeing the value of the plan were probably enhanced by the fact that there were no requirements for following up on the plan nor evaluating lessons learned in a final report. A bit more information and hints on time usage and perhaps also changes in the required form of the time plan could give a more realistic time plan resulting in a more structured work.

A little bit more guidance in the modelling task may be needed. One could think of more lectures content on modelling combined with a compulsory supervisor meeting to discuss the model at an early stage. This would also probably help to avoid some confusion and reduce the total time usage. On the other hand it is important to leave the implementation completely open.

In fact we would like to see some more unorthodox solutions such as attempts to make a piezo-based or electrostatic loudspeaker. Hinting at such possibilities in the introductory presentations and changing the teacher prize from "the best loudspeaker" to the "most innovative loudspeaker", may also promote this. However, we realize that this is perhaps the drawback of choosing a task based on a relatively well-known device: "everyone knows how a loudspeaker works."

Already at the present course round we plan to adjust the grading, so that also students in teams that have not received any of the distinctions for "best loudspeaker" have a fair chance of getting an A. The competition should be an extra encouragement, not the way to achieve an A grade.

CONCLUSION

The project course has achieved the main goal set at the program level, i.e., to strengthen the profile of the electrical engineering program. This by visualizing for the students what kind of work an electrical engineer actually does and how the theory taught in the courses on electrical magnetic field theory, circuit analysis, mechanics, etc., relates to the functionality of an everyday used device.

From an intended learning outcome perspective, the course has partly helped the students to reach the goals that were set. The student have learned to approach an engineering problem from a system perspective and to take the theories taught in the different courses and bring them together to model the functionality of a system composed of several parts. However, the course has not fully reached the goal that students should learn to apply their theoretical results when designing the hardware of a system. To achieve this, the system specifications in the project specification most set at a level so that the students have to apply the theory in the hardware design to meet the system specifications. Further, learning activities that helps the students reflect and analyze the outcome of the hardware designed to their theoretical model of the system should be introduced.

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