An Inspiring BSc-EE Curriculum for Science and Engineering

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***Abstract*—In this contribution, we will present the design, implementation and first results of the BSc program in Electrical Engineering now in place at Delft University of Technology. It is a general curriculum that prepares students for a wide range of MSc-EE specializations, including microwave related studies.**

The curriculum is designed to provide a transparent structure with clearly recognizable subject threads, one of which is 'projects'. As such, the curriculum offers the students a challenging project each semester, in which they work in teams to apply, enhance and integrate the knowledge from the theory courses that run in parallel or are prerequisites. Intentionally, but to a limited extent, students also discover new concepts before they are treated in a course. The projects provide a path from close-guided semi-practicals to distance-guided projects without a predefined outcome. By design, the projects aim to be inspiring, make the study attractive, promote student learning and show the broad range of aspects covered by Electrical Engineering.

As for the relevance of project contents for the field of EE science and engineering, the projects contain a.o. amplifiers, power supplies, audio filters, metal detecting sensors (designed and built by the students), integrated circuit design, transmission lines, radar and communication concepts, sensors for obstacle detection, and contactless charging.

I. INTRODUCTION

Electrical Engineering is in many ways a fascinating subject. It is at the core of engineering, and arguably an extremely important enabler and catalyst of technological progress in many other fields. It is not without reason that Electrification is placed number one on the list of greatest engineering achievements of the 20^{th} century [1]. Moreover, positions 5, 6, 8, 9, 13 and 15 on this list are respectively taken by Electronics, Radio and Television, Computers, Telephone, Internet, and Household Appliances. Other technologies such as Automobile on place 2 are not by nature electrical, yet current automotive technology improvement is largely driven by electronics such as sensors, actuators and embedded computers with the associated software. In fact, no item on the list does not benefit tremendously from electrical engineering achievements–consider Health Technologies on place 16.

Yet, the number of students in the Netherlands that enroll in an academic program in Electrical Engineering has been decreasing over time. See, for example, Figure 1 that draws from data from Netherlands Statistics [2] to show the dramatic fall in the percentage of students that enroll in an EE curriculum at any of the three Technical Universities in the Netherlands that offer such a program. The fraction taken is relative to the number of enrollments in any academic program nationally. In essence, this figure has steadily decreased from 1.69% in 1990 to 0.45% in 2007. Moreover, similar trends are shown by comparison to enrollments in other technical studies in the Netherlands. Figures in many other developed countries are in general showing the same trends, possibly more so in the Western world.

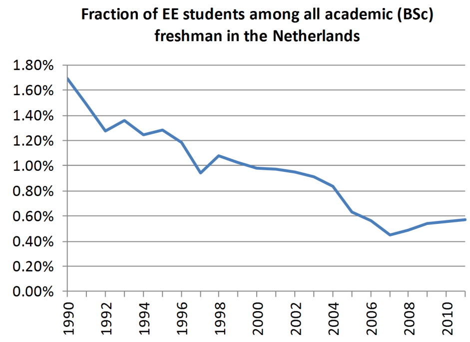


Fig. 1. The fraction of students in the Netherlands choosing an academic BSc program in Electrical Engineering versus all students enrolling in an academic program. Source: [2]

While it is hard to obtain conclusive evidence about the underlying reasons for such trends, a number of hypotheses are popular. These include the perceived invisibility of Electrical Engineering in many instances. An iPhone or a kinect game is not readily understood as something that is tributary to a lot of EE. In fact, EE partly is rather abstract and invisible by nature. Consider the field of Signals and Systems which is often more like applied mathematics than it is like (hardware) engineering.

Having recognized this trend, and perceiving both a threat for its own existence as well as a greatly unsatisfied need for EE graduates in society, the faculty of EEMCS commissioned a number of working groups to analyze the situation and prepare for a revision of the BSc EE curriculum in TU Delft. This preparation included 'looking outside' to identify trends and compare peer curricula. This process has a.o. resulted in an assignment for a subsequent curriculum design committee [3]. The aim was a new, modern curriculum of high quality, that is capable of attracting students by clearly connecting to practice and society.

II. CURRICULUM DESIGN

The assignment [3] mentioned above includes a number of curriculum design principles, excerpted as follows:

1) Create a broad measure of integrating projects, both at the beginning of the study and in the second and third year, with a clear view of the societal context of electrical engineering.
2) Make sure the training is broad. Also, allow students at an early stage to become acquainted with the information-oriented areas of electrical engineering. 'Programming' should come early in the curriculum.

The result has become a curriculum in which integrating projects play a key role. See Table I. Each of the semesters in the first and second year includes a semester-long integrating project. The first semester of the third year is completely occupied by a *minor*. Subsequently, the first half of the second semester is exclusively devoted to theory courses and the second half exclusively to the BSc graduation project. The design of the curriculum is presented in [4].

The projects are designed to become more challenging from the first to the last, from partly close-guided practical style towards distance-guided projects without a predefined outcome. They link theory to practice, integrate theory between subjects, allow/stimulate practicing with the theory but also introduce general/academic skills (such as oral presentation, team work, problem description and analysis) and professional/engineering skills (such as soldering, matlab, simulink) and allow students to practice these skills.

Typically, these skills are introduced through 'just-in-time' drills. These are tutorial-style lectures or self-study units, that offer these new knowledge or concepts immediately before the students will naturally need or use those concepts for the project work. Some drills also prepare students to work a subject (e.g., opamps) in a more descriptive style before the subject is taught in the theory classes.

While the above refers to the current curriculum, a revision is currently underway, to be implemented in Sept. 2013. Because of stricter performance agreements between the government and the universities in the Netherlands, basically all universities are implementing measures to improve study success. In TU Delft, this has resulted in new university policy giving stricter guidelines for the structure of all BSc curricula. For EE this means that course units will be refactored so that no more than 3 subjects (course modules) run concurrently with the project. Because it is expected to increase focus of students, this is seen as an improvement from the current situation where 4 subjects plus the project can run concurrently.

TABLE I
BSc CURRICULUM BY SEMESTER. EC REFERS TO NUMBER OF CREDIT POINTS ACCORDING TO THE EUROPEAN CREDIT SYSTEM, WITH 30 CREDITS PER SEMESTER. PROJECTS ARE IN ITALICS. THE MINOR IS COMPLETELY ELECTIVE, AND CAN'T INCLUDE EE SUBJECTS.

Semester 1	**EC**	**Semester 2**	**EC**
Calculus	6	Calculus & Statistics	6
Linear Algebra	3	Electricity & Magnetism	5
Physics	4	Semicond. & Electronics	4
Circuit Theory	6	Digital Systems	5
Programming in C	3	Instrumentation	2
Booming Bass	8	*Smart Robot Challenge*	8
Semester 3	**EC**	**Semester 4**	**EC**
Complex Analysis	3	Differential Equations	3
Linear Algebra	3	Digital Signal Processing	3
Integrated Circuits	4	Stochastic Processes	3
Signals and Systems	4	Dynamical Systems	3
OO Programming	2	Electric Energy & Sustainability	4
Telecomm. Networks	2	Telecomm. Techniques	6
El. Machines & Power Conv.	4	*Electric Mobility 2020*	8
Design a Chip	8		
Semester 5	**EC**	**Semester 6**	**EC**
Minor	30	Electromagnetic Waves	4
		Computer Architecture	4
		Analog Electronics	4
		Control Systems	3
		BSc Thesis Project	15

III. Electrical Engineering Projects

In this section, we will describe the projects in an informal fashion. Due to a lack of space, we will omit connections to learning goals and exit qualifications and a discussion of the BSc thesis project.

A. Semester 1: Booming Bass

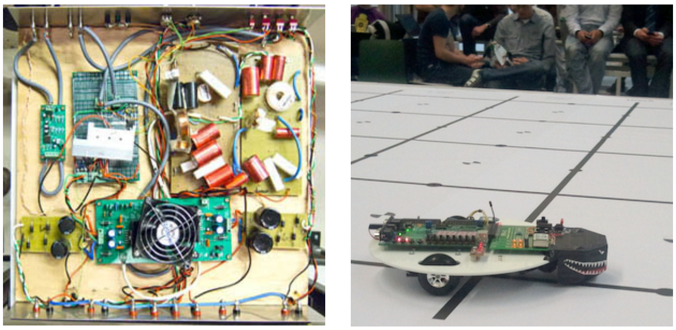
The students start in the first semester of their freshman year with a project of which the name can be translated as 'booming bass'. The project aims to help students understand what EE is all about. It should give students an early indication whether or not EE is the correct field of study for them, and should really motivate and inspire students for which it is. As one means to achieve this, the project embeds mini presentations by students on current topics of EE as selected by the students. This is naturally coupled with practicing of presentation skills.

However, the main theme of the project is audio, and the students start in week 1 with building noise-canceling headphones. This part is not yet strictly integrated with the concurrent theory classes, but gets them started in a fun electronics project. They learn and practice measuring, soldering and other basic skills, and at the same time are exposed to more abstract concepts such as signals and waveforms.

Subsequently, they move on to design and build a power supply unit, amplifier and crossover filters for an audio system. The theory that they need is partly synchronized with the concurrent classes on circuit theory, calculus (complex numbers) and linear algebra (solving systems of circuit equations). For the latter topic they use Matlab, which is very naturally introduced as an essential EE engineer's tool.

While all of the above is giving the students freedom to make choices (and mistakes), the specifications of what needs to be designed are given. However, when the basic system is ready, the students are challenged to become creative and improve the bass response of the system, without strict requirements. Often they add just another more powerful amplifier with a different crossover. However, some more advanced (and more successful) solutions are sometimes proposed and implemented, including a Linkwitz-Riley transform circuit [5]. Figure 2 (a) shows an example system as built by the students.

The project is concluded at the end of the semester with



(a) (b)

Fig. 2. (a) A 'typical' 1^{st} semester project built, with power supply, crossover filters and amplifier plus an actively cooled 'booming bass' extension. The frame/chassis is provided to the students. (b) The robot of the 2^{nd} semester project during the final competition.

a symposium where the students present their work, with particular emphasis on the design process and the design choices that they made. There is also a 'sound-off' where the final products are compared on sound quality, with and without the bass extension. It is often amazing how different the loudspeakers (identical enclosures with identical drivers) sound. These differences are discussed with reference to the design choices and the measurement results that the students have to present.

B. Semester 2: Smart Robot Challenge

Whereas the first-semester project focuses on application of circuit theory concepts, the second-semester project is mainly driven by concepts from Digital Circuits. However, the project also integrates objectives from the concurrent Electronic Instrumentation, Statistics and Electricity & Magnetism classes.

In this project, the students first need to implement an FGPA-powered optical sensor based line-follower that is capable of following a line drawn on the playing field. Subsequently, the students will add a self-built metal detector device to search for mines as proxied by metal coins. The project concludes with a contest to test and compare all robots. Figure 2 (b) gives an impression of the final competition.

The metal detector can use either a inductive or capacitive sensor, and is designed and constructed by the students using theory from the concurrent course on Electricity and Magnetism. The read-out electronics is developed using theory from Electronic Instrumentation, and is typically constructed using a relaxation oscillator that detunes upon detection of the object. The detuning is detected in the digital domain.

C. Semester 3: Design a Chip

This is the longest running project which has survived a number of curriculum revisions. Over the years, it has been adapted both to incorporate more modern software tools and to include new learning objectives as they were modified to fit revised curricula.

In this project, the students design a chip. In groups of about 10 students they design an integrated circuit, from concept to tape-out. The chips are semi-custom Sea-of-Gate (SoG) chips [6]. Such technology is not current anymore, but still useful and economic for the purposes of the project. A SoG chip is a half-finished chip, with the transistors being all preplaced but unconnected and the chip function being mask-programmable via the metalization layers. This metalization can be done in-house at the DIMES semiconductor research and prototyping facility of TU Delft [7] with short turn-around time.

Compelling reasons to go with real chip fabrication rather than more modern Field Programmable Gate Array (FPGA) solutions include the following:

1) Compared to FPGAs, students are exposed far more to physical limitations and properties, e.g. related to routing, placement and interconnect delay.
2) Compared to reprogrammable solutions in general, students are forced to have everything right after the design is finished, and students are forced to rely on modeling and simulation rather than trial and error. If the design is wrong at tape-out, it can't be corrected anymore.

Also, students are motivated a lot by the prospect of seeing their own chip under a microscope and to test it.

The design flow is from VHDL to layout, partly using standard tools and partly using home-grown software. In this flow, FPGAs are actually used for prototyping.

In the first years of the project, students were given a short description of the chip to make. Students can still choose pre-cooked ideas, but typically they prefer to come up with an idea of their own and to outvie their predecessors. Figure 3 (a) shows a resulting working game of Pong.

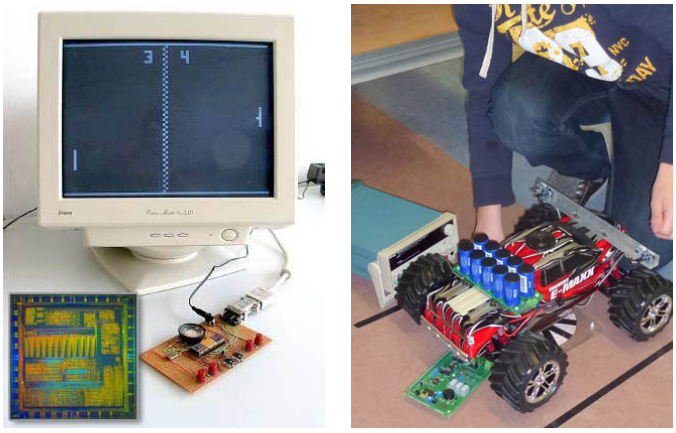
D. Semester 4: Electric Mobility 2020

This project shows the strongest connection to the surrounding theory topics, which include signal processing, electronic power processing, telecommunications and dynamic/control systems. These courses allow experimenting with concepts of modern traffic systems, such as connectivity and autonomy. The project focuses on a robust 'monster truck' model car which is modified to run on an array of supercaps rather than batteries. See Figure 3 (b). The car is furthermore equipped with sensors for collision avoidance, a Zigbee radio for receiving control signals and an audio beacon. The car enables contactless charging via resonant inductive energy transfer.

From the students perspective, they built an efficient contactless charger, an anti-collision radar using the sensors and a localization system for the car using the audio beacon. Localization is achieved via five microphones at fixed locations on the floor of the room, receiving audio pulses emitted by the beacon to determine the location via Time Difference of Arrival (TDOA). In the final competition, the car needs to fulfill a couple of challenges including driving autonomously to a certain destination across a field with obstacles.

IV. Results

The freshman (propedeutic) year of the new curriculum ran first in the academic year 2010/11 while it ran for the second time in 2011/12 concurrently with the first run of the renewed



(a) (b)

Fig. 3. (a) The result of a 3^{rd} semester project, a student-designed fully functional Sea-of-Gates chip implementing the game of 'Pong'. The output of the chip is VGA compatible, it is mounted on a montaprint board with just a crystal oscillator, a speaker and 4 push buttons. The inset shows a microphotograph of a finished chip. (b) A model car for the *Electric Mobility 2020* semester 4 project during the final contest. One can see the coils for wireless charging, an array of supercapacitors for energy storage and the sensors.

sophomore (second) year. The renewed third year will run for the first time in 2012/13.

Qualitative information on the success of the curriculum is a.o. collected via a system of class response meetings. This entails formalized quarterly meetings with student delegations from each cohort and the curriculum management, without lecturers. Also, questionnaires, feedback received by student counselors and the impressions and signals received by the student mentors are used as qualitative data. Course statistics provide quantitative data.

The new curriculum was designed to be motivating in the eyes of newly enrolled students, by showing them as early as possible what Electrical Engineering entails. We certainly believe that this goal has been achieved, although evidence is mostly anecdotal. That is, students *tell* us that they like the projects in general. For the first semester project in particular, the students also tell us that they appreciate the view of electrical engineering that is brought to them and what they discover themselves via the mini presentations. Students also acknowledge that increased awareness of EE is also stimulated by connecting the 'practical', 'hands-on', tinkering stuff to theory. The students need to go through calculations and they have to show understanding and insight, before they are actually allowed to build things and before their contribution can be accepted for a pass.

The opposite goal, that of allowing students to make an early informed decision on leaving the EE training also seems to be realized. Students who are in doubt, usually seek contact with their mentors, the student counselors or the tutors of the first semester project. In such discussions, lack of motivation for the study can often be attributed to changed perceptions of EE or of an academic curriculum in general. In the latter case, students can decide to enroll in a polytechnic program for EE. Of course, there can be a host of other factors impeding study-motivation or study-success, including long commutes and student life.

TABLE II
BREAK DOWN OF NUMBER OF STUDENTS FROM COHORT 2010 ABOVE OR BELOW 30 EC THRESHOLD, W.R.T. SUCCESS IN SEMESTER 1 AND SEMESTER 2 PROJECTS. SEE TEXT.

	$\geq$ 30 EC	< 30 EC	
Project	S2 pass	S2 pass	S2 fail
S1 pass in 1	53	4	2
S1 pass in 2	4	4	2
S1 fail	0	3	2
S1 no attempt			14

In TU Delft, students need to achieve at least 30 EC (45 EC in 2012/13) in their first year, or they are not allowed to continue their studies. The new EE curriculum seems to improve on this compared to the previous curriculum. In particular, 53% of the students passed this threshold in 2009/10, and 63% in 2010/11. These numbers are still low, but not uncommon in TU Delft. (The average over all BSc curricula in 2010/11 was 68%.)

Table II shows the grade statistics for the projects of the first year. The semester 1 project has an oral exam, with 59 students passing in the first attempt (see first row), 10 students needing a repeat, 5 students failing and 14 not attending. Clearly, students who need only one pass have the biggest chance of passing the semester 2 project and of achieving the 30 EC threshold (53 from 59). Only 4 from 10 students who needed the semester 1 repeat, achieved the 30 EC threshold. Also, only 3 students who failed the first semester project could pass the semester 2 project, but none of them reached the 30 EC threshold. As such, this data seems to confirm that the semester 1 project fulfills its role of being selective.

V. CONCLUSION

This paper has described the role of integrated projects in the BSc EE curriculum at TU Delft. They are designed to be inspiring and motivating. By clearly displaying the breadth and beauty of the field they help to attract and retain the right students. While the limited quantitative data that is as available as of yet is (only) mildly positive, the qualitative impressions obtained so far are certainly encouraging.

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