Adapting to a changing highschool population

Changes in the EE curriculum resulting from math and physics deficiency

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Abstract—**This paper reports the recent changes in the EE Bachelor program at the University of Twente. Recent generations of freshman students exhibited a lack in mathematics skills and the ability to grasp the physics behind the equations. By starting of the curriculum with a new course "Introduction to electronics and electrical engineering (IEEE)" we have managed to solve the issue of lacking entry levels while simultaneously eliminating the unmotivated or under skilled students in a very early stage in their studies.**

I. Introduction

Due to a change in the Dutch secondary school exam requirements all technical bachelor studies suffer from a discrepancy between the traditionally expected entry levels and the actual knowledge and skills of their freshman. In secondary education the number of hours for physics and math has been reduced and in the mean time there is a growing emphasis on project work, presentation skills, learning to find information and teaching topics that are of social interest (solar cell, global warming). The changes in the high school programs aimed at giving all students, basic math and physics knowledge making math a mandatory part of the exam like Dutch and English language courses. The undesired impact of replacing old fashioned exercise work with project work and computer simulations is that a large portion of the high school population is no longer able to do mathematical manipulation without a graphical calculator. This unfortunately includes some of the students who take up a technical bachelor study. Additionally for good students the high school program is set up so they can finish all assignments in class, resulting in a generation of students that are not accustomed to do homework or work more than 25 hours per week. The present generation of students holds a larger than before percentage of students that consider a pass grade sufficient, nicknamed "the MTV generation attitude".

Fortunately there are still highly motivated and well skilled students graduating from high school with A-level grades as well. This means that any academic education has to deal with a large variety in the level of knowledge and skills when the students start their bachelor studies. Considering the dropping interest to start a career in (electrical) engineering keeping the old BSC EE curriculum and accepting a very large dropout percentage is not an acceptable solution. Therefore at the University of Twente we have decided to change our curriculum by adding an introductory course in the beginning of the first semester. The course "*Introduction to Electronics and Electrical Engineering", IEEE*) should help motivated students pick up the required level and the pace of studying. For those students that do not suffer from a lack in knowledge or skills the course offers the opportunity for to dive deeper into the theoretical background and learning analogies in other technical fields.

II. Aspects of the new IEEE course

The freshman course IEEE has a study load of 8.5 European credits (240 hours). Apart from solving deficiencies in math and physics knowledge and skills it helps students adapt a new work attitude and should work motivational. The course consists of lectures, blocks were students can make exercises (supervised/assisted by teacher), lab works and a final project to integrate the gained knowledge and skills.

Like any class the students encounter the following phases [1]

- Orientation
- Gaining knowledge
- Making it operational
- Testing
- Reflection

The special part of the course IEEE is that we give an orientation for the entire bachelor program.

A. Mathematical skills

The math skills of all engineering students at the 3 technical universities in The Netherlands is tested in the first week of the semester in a multiple choice test covering high school topics in general algebra, logarithms and powers, goniometric relations and differentiation rules. The test was originally intended as a diagnostic tool. Cleverly chosen wrong answers hinted towards specific problems in the mathematical manipulation skills, see for example figure 1.

The expression $2\ln(p) + 2$ can be rewritten as:

a)	$\ln(p+2)^2$	$\ln p + 2 \neq \ln(p+2)$
b)	$(\ln(pe))^2$	$\ln(p^2) \neq (\ln(p))^2$
c)	$2\ln(pe)$	**Correct**
d)	$\ln(p^2+e^2)$	$\ln A + \ln B \neq \ln(A+B)$

Figure 1. Multiple choice question and the possible thinking errors

The average score per specialization varies between 35 and 65 %, the highest for the math students. These numbers indicate that the math proficiency is not the determining factor in choosing a career in a technical field.

In interviews, students frequently indicated that they had simply forgotten the knowledge during the long summer break or that a test in the first week of the semester does not give a fair result since they are still getting settled in their new living situation. The first excuse was tested by giving the same test to high school students (with a profile that would qualify them for an engineering study) just after graduation (before the summer break). The results were similar to the freshman results. The second problem was overcome in 2009 by moving the test to the second week of the semester, giving students the possibility to prepare for the test. Although the results did improve slightly, a large majority still did not pass the test despite passing the high school exams.

After having identified the most common deficiencies, a university wide so-called repair course in high school mathematics for those students who fail the entrance test was instated where students could practice numerous exercises to prepare for the second test, 5 weeks later, using a specially developed textbook [2]. Consistently over the period between 2005 and 2009 students in mathematics and applied physics score the best at the entrance test, EE is in the second group.

The second test after the repair program shows an improvement in both the number of correct answers as well as the percentage of students that pass the test, see figure 2. For studies without mandatory repair course the improvement is less and only few students actually follow the program and take the second test. This again indicates that students do not perceive it as a problem when their basic math skills are insufficient.

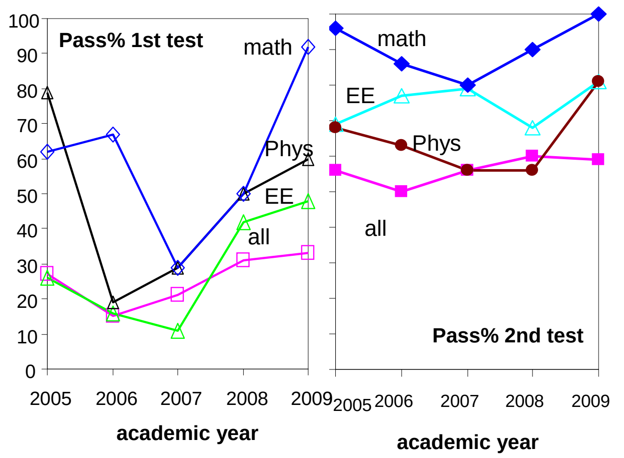

Figure 2. Percentage of students that pass the first (left) and second(right) algebra test for electrical engineering, applied physics, mathematics and all engineering students in the period 2005 to 2009. The repair program is mandatory for EE, Math and approximately 60% of the entire population. It is on a voluntary bases for physics students who fail the first test.

B. Physical insight

A considerable part of the students consider equations as expressions that can be solved using a calculator. The basic knowledge that equations are a description of the physical relation between parameters is taught in school, but since both a graphical calculator and a summary book with equations can be used during the exams the importance of the physical relations does not sink in with the majority of the students.

A second problem that has surfaced is the fact that not all physics knowledge that has to be taught in high school will be part of the exams, and this is known to both teachers and students. This leads to a population of students with a more mixed knowledge. Now not only do students have different high school physics grades indicating different levels of understanding but also depending on their teacher some topics might be sacrificed due to lack of time.

In the course IEEE we intend to deal with difference in physics entrance level treating each topic as “new”, making sure that also for the “good” students there is indeed something to be learned. For example when introducing a resistor in the first lecture we show the different symbols you might find in textbooks, explain that also the connecting wires have a resistance, and that real resistors are temperature dependent.

C. Work attitude and motivation

The curriculum EE is based on a 40 hour work week for the average student. If students do not put in sufficient hours from the first day for their studies a large portion loses the first year al together because they never catch up anymore. Without making attendance mandatory, since this would contradict the learning academic skills idea, we create a program that entices students to put in the required hours. We have allocated a significant portion of the course to lab work. The classes and lab work are intertwined in such a way that the students are motivated to attend class and make the exercises since failure to do so either makes them fail the lab courses, or gets them a just pass grade but they have to miss the “cool” part of the lab work due to lack of time to finish the experiments.

In this freshman class we give and introductory overview of a large part of the bachelor program. This includes topics that are in depth taught in the final stages of the studies. The exam questions on these topics are at the introductory level, but the lab work is much more specialized. In contrast to the old curriculum where the lab works followed the lectures, and was kept to the basics. We now are able to give an outlook over the entire working field of our future graduates. This should have a long term motivational effect. In the first year we introduce the concept of Fourier analysis and show its use for communication systems. We hope this motivates students to work more actively in the second year math course that deals with this topic since they know they will need it later for the telecommunications class.

Next to the motivational aspects for the students the very early overview of the entire curriculum has a second benefits. Students can switch earlier to another education in case the content of the study is not what they expected or the study load or the study pace is heavier than anticipated. Before the introduction of the IEEE-course students would start with background calculus classes and more abstract EE courses. The first electronics class with immediately visible practical applicability would start only in December (academic year starts in September).

It has to be noted that keep the students motivated we have abolished the words, math repair, math deficiency etc from our vocabulary in all teacher-student interactions. As far as the students are concerned we teach the necessary skills for their engineering career. The repair topics of the algebra/math are integrated in the course the same way as the new math they learn (e.g. 2nd order differential equations)

III. RESULTS OF IMPLEMENTING IEEE COURSE

A. Mathematical skills

For EE we have decided to fully integrate the algebra repair classes in the introductory electronics course (IEEE) starting in September 2007. The order of the topics in the math-repair-lectures is synchronized with the topics in the electronics class. For example, we teach manipulations with fractions when series en parallel networks are taught, and exponents in parallel with RC networks. We have also decided that the grade obtained for the algebra test makes up 17.5% of the final grade for the course. In addition we count the highest grade for the algebra test motivating students who have passed the first test to keep following the classes and try to better themselves the second attempt. For the 2007 and 2008 generation more than 90% of the students who passed the first test also took the second test. For the 2009 generation this was only 35%. This might be cause by the fact that the second test was shifted one week back due to the shift of the first test to the second week. This meant that the algebra was just before one of the IEEE mid term tests.

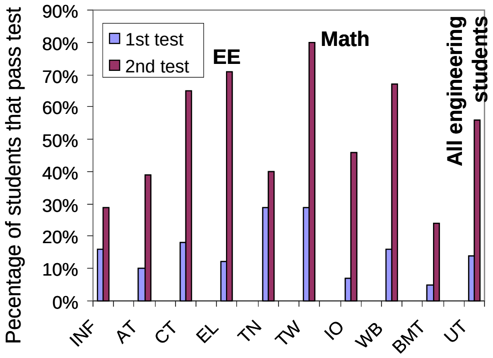

Figure 3. Improved math proviciency for 9 enineering studies (2007).

After 5 weeks the second test is taken to investigate the effect of the math repair program. In the 3 years that the math repair was fully integrated in the IEEE electronics classes more than 80% of the EE students pass this second test. This is second only to the math students. Other populations do show improved results but significantly less than the improvement for EE (figure 3). It should be noted that in 2007 we had replaced most of the algebra exercises used by the other engineering studies with examples from electrical engineering. In 2008 and 2009 we have used the exercises given in the book but we did keep the synchronization with the EE topics.

The results in the improvement of the algebra test and the attendance level in class were comparable indicating that students fortunately do make the link between generic adding with fractions to the applicability in calculating resistive networks.

Figure 4 shows the correlation between the high school math grades (perfect score 10) and the results in the algebra tests (22 multiple choice questions). 13 correct answers was considered pass. The number of correct answers increase, and repair program levels the “slope” of the graph. This is partially due to drop out of students with poor scores. But it is clear the students that scores poorly at the first test do improve after the refresher course.

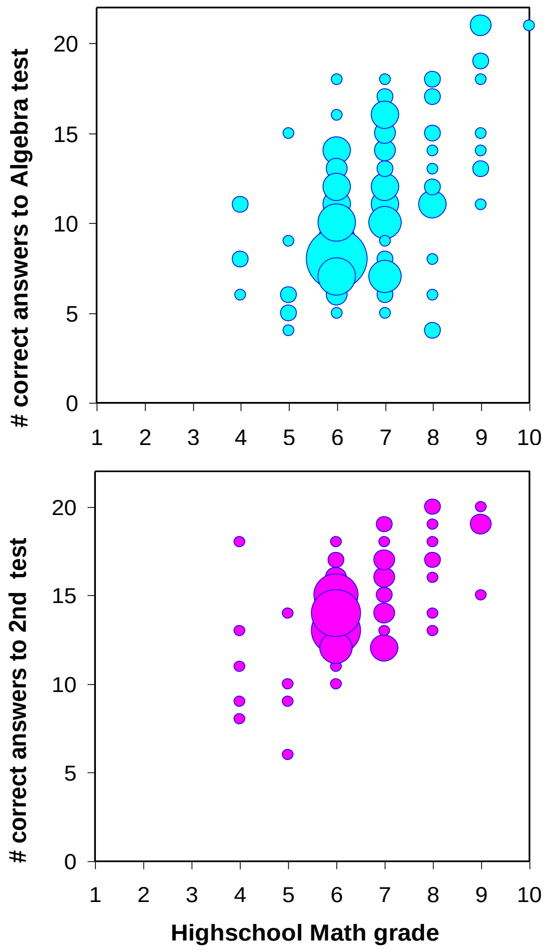

Figure 4: Correlation between the high school math grade and number of correct ansers on the algebra test (max 22) for EE students from 2007-2009. The bottom graph shows the results after the repair lectures. The number of students for the second test was lower since it was not mandatory to retake the test after passing the first test and some students had dropped out.

Figure 5 shows the grades for the first EE course (top) and the first university level math course, Calculus I, (bottom). The level of the math after the repair course (2nd test) shows a good correlation with the first EE course. However for Calculus I there seems to be a correlation with the first test. This may be due to the fact that students underestimate the calculus class because of their large improvement in the algebra test. We can not exclude the possibility that students like the new course IEEE so much that they spent relatively little time on the parallel course Calculus I. In this case only the students that are already good and motivated, i.e. those with good high school grades and those who score good on the first test also pass this first university level match course.

From figure 4 and 5 it can be seen that high school math grades are still a good predictor of the results at university level. Although there are always exceptions as can be seen from the large band of results, a 7 in math is a good basis for the EE curriculum.

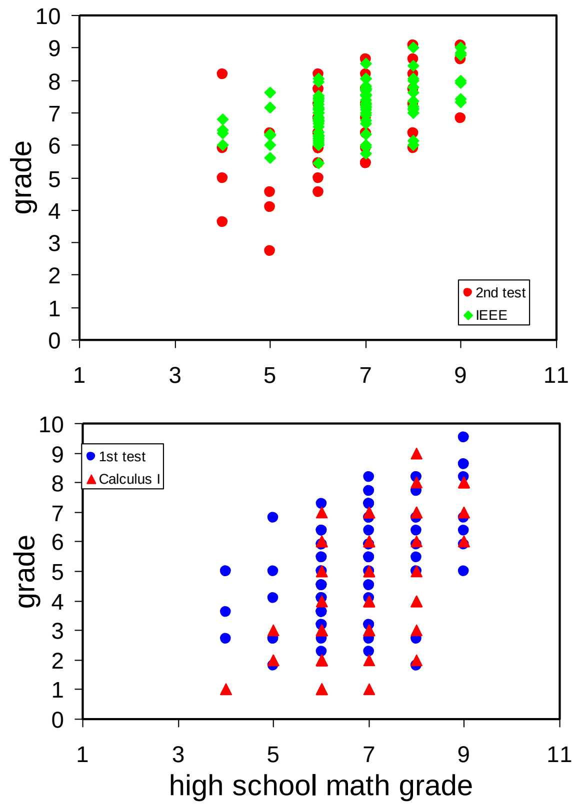

Figure 5: Top grades obtained for the 2nd algebra test (after the repair program) and IEEE, the first EE course. Bottom Grades for the first calculus class and the entrance test in algebra.

B. *Physical insight*

In our newly developed course start with an observation from nature (a capacitor can be charged resulting in a voltage) and work our way up to the describing relation. We also show a large number of physical systems that show the projection to other physical fields where similar behavior can be described with the same mathematical equations. Understanding the mass-spring system helps understanding electronic oscillations. Traditionally only in the third year of the studies these analogues are taught so that students can describe and understand physical systems with equivalent electronic circuits. We believe that in the beginning of the studies the reverse might be the case. By explicitly showing the route to the final system (starting with Hooke's law, ending in a differential equation) the students familiarize themselves in manipulating relations, lowering their dependency on graphical calculators.

During most lectures we show physical demonstrations of certain effects, RC delay related with thermal resistors and capacitors, oscillations in two communicating water vessels, breaking a glass at its resonance frequency, transmission lines with deliberately created imperfections in it etc. When physical demonstrations are not practical we show computer simulations.

C. *Work attitude and motivation*

There is a direct impulse to the students that although math might be perceived to be boring (65% of the students) it is useful (80% of the students). We have also deliberately created assignments that can be relatively easily solved if you understand the theory, but are very hard to solve when you don't grasp the underlying physics and have to do tedious calculations or derivations. The students indicate that they do indeed put in the hours, 80% of the students puts in between 90 and 115% of the study load. This shows that the students are motivated to work hard for topics that are of interest to them. This also means that present day students are not "stupid" but they are on average lazier than previous generations and an external motivator is needed instead of an internal drive.

As mentioned above we do not have sufficient data for the amount of time students spent on parallel classes like Calculus. We can say that the way we teach our course motivates students to put in approximately the study load, but if their workweek actually is increased to 40 hours remains unclear.

The course IEEE ends with a final project; the building of a solid state weather station. Groups of four students make a temperature sensor, a wind-speed sensor, a wind direction sensor and a humidity sensor. They can not all be based on the same measurement principle (capacitive, resistive). Apart from the sensing, also the data transfer and (USB) read out is part of the final product. Students indicate that they are highly motivated because of the project. Most students like the freedom they have in choosing their solution to the sensing challenge. In addition the competitive element of coming up with a more clever solution then the other groups works very motivating. There are bonus points to be gained for extra good results. The wind-speed sensor can for example be tested up to hurricane speed (see figure 5).

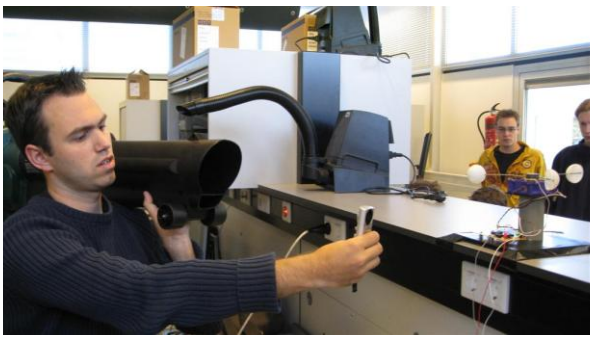

Figure 5: The final product is tested under extreme conditions

The course IEEE is intended to give the students an overview of their bachelor program and thus work motivational for the rest of the studies. Since it is an introductory course, all students who are motivated should be able to pass. We increase the chance of passing by not giving one final exam but three intermediate tests. This serves as a motivator to put in the time and as a wake-up call when the first test was underestimated. This way the students get quick feedback. For the generations 2007 and 2008 we managed to get 100% pass level for the students that remained in the EE studies. All students that did not pass went to other fields.

D. Drop outs and impact other courses

One of the intended effects of giving and early overview of the content of the entire bachelor program is that students who have chosen the wrong career are able to switch early on. For the 2007 and 2008 generations 25% of the students that start stop in the first year. 70% of the students who drop out in the first year leave before February 1st. The other 30% finish the first year and switch in the summer break. From older generations we were not able to trace back when the students stopped since only the year is recorded. It is known that there were also still students switching in the second or third year. For the 2007 generation this was not the case (so far) and we will continue to monitor this aspect.

Upon the introduction of IEEE in our curriculum the percentage of students passing the other courses in the first semester increased, but the observed effect is within the year-to-year variations.

A result of teaching a course with a lot of student-teacher interactions is that the students are motivated to work hard. A side effect is that for courses that follow in the rest of the first year the students have to learn academic skills like planning, studying without a teacher (do homework) and self motivation. The course "Network-analysis" has shown a clear correlation between the students who prepare for the exercise blocks and the grade in the exam. Students who prepare at home can use the time in class to ask questions and keep the pace of the lectures. The students that do not make homework loose the first half of the interaction time in trying themselves and have insufficient time in the end. This results in lower grades, usually failing the exam. Students who do not attend at all typically realize too late that they needed the help of the teaching assistant. They fall back so far that they usually do not even attempt the exam and have to repeat the next year.

IV. IS THE DESCRIBED APPROACH GENERALLY APPLICABLE?

The University of Maastricht attracts a lot of German students due to its border location. Their comparison of the algebra level between Dutch and German high school students summarized in table 1 indicates a higher score for some German secondary education tracks but the general lowering of math skills does not seem to be a typical Dutch problem.

Secondary school education		score
VWO B12	Dutch, math at level needed for engineering studies	48%
Grundkurs exam	German, basic math	45%
IBMathHL	International, extensive Math	55%
Leistungskurs	German, extensive Math	58%

TABLE I. : SCORES ON ENTRANCE ALGEBRA TEST OF STUDENTES ECONOMY AND BUSINESS ADMINISTRATION AT THE UNIVERSITY OF MAASTRICHT FOR SEVERAL HIGH SCHOOL EDUCATIONS [3]

The changes in our curriculum were a result a change in the Dutch school system combined with the attitude of young people to be happy with a pass grade. In a number of European countries this is a relevant topic. Motivating the students to work hard is necessary for all teachers. Some universities have the luxury of being able to select only the best students, e.g. in countries where a higher education is your only ticket out of poverty. Although the described approach might be less relevant for them, still intertwining theory, practical assignments and math education in the engineering classes may enhance motivation of the students.

V. SUMMARY AND OUTLOOK

In several European countries the numbers of electronics and electrical engineering students are dropping. By keeping the students motivated the dropout numbers can be reduced while still maintaining the same standards for the BSc degree end-terms. We have chosen to do this by integrating math and algebra lesions in the electronics classes in combination with a totally intertwining the lectures and lab courses. Our approach has resulted in a significant increase in the math proficiency test. Also the following electronics classes in the first year have an increased pass percentage. The gradual transition from renewal of knowledge that is (or might) already be known to part of the population to new topics allows us to quickly adapt to upcoming changes in the high school math and physics program. By shifting the emphasis of the lectures or include new subtopics we will be able to deliver a more homogeneous population to the teachers of the other EE classes.

ACKNOWLEDGEMENTS

This work was partially funded by a grand from the Nationale Kennisbank Wiskundevaardigheden (NKBW-I) and a contribution from "WO-Sprint". We thank Steffen Postuma, Brigit Geveling, Luuk Spreeuwers, Wouter Olthuis, Anne Johan Annema and Ronan van der Zee for fruitful comments.

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