CDIO SPIRIT IN INTRODUCTORY PHYSICS COURSES IN ENGINEERING

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ABSTRACT

All first year engineering students at Reykjavik University take two introductory physics courses. In these courses the physics teachers have been introducing the basic physics in the traditional fashion, but have also incorporated to some extent the elements of engineering in the CDIO spirit by adding to each course a small challenging project. Students do two practical projects, in addition to several well structured lab experiments. In Physics 1 (mechanics) they have to conceive and design their own experiment in mechanics, perfom it, measure and analyse the dynamics quantitatively, and produce a report. Projects have included analysis of various oscillations, braking, projectile motion, Bernoulli effect, collisions, etc. The main idea is that they receive only minimal supervision from the teachers and do the work on their own. In Physics 2 (electromagnetism) students have to design and construct a small electrical device. They are given a very brief description of what the device is supposed to do. The students have to show up with the working device, explain it using the theory they are learning and demonstarate that it actually operates. The workmanship affects the grade. The devices must be constructed from scratch and may be done at home, but the students may use the facilities at the University, like the electronics lab or the machine shop. Projects have included making electric motors, stepper motors, relays, dynamos and loudspekers. Students are generally quite enthusiastic about these projects, they enjoy the opportunity and challenge to construct someting on their own and realize that cooperation is beneficial. Each project is typically done by a team of two students. This fall we started implementing this kind of free projects in the third physics course, which covers optics and modern physics, and is taken by some students in the third year.

KEYWORDS

introductory physics, independent labs, projects, device construction, standards: 4, 7 and 8.

INTRODUCTION

All students in engineering at Reykjavik University (RU) must complete two introductory physics courses in their first year in the BSc program, covering mechanics and electromagnetism. These students are in biomedical engineering, engineering management, financial engineering, mechanical and mechatronic engineering. At the same time they take several courses that form part of the theoretical foundation for the engineering progaram. Table 1 shows the structure of these programs for the first year in the BSc-program in engineering. These courses are taught in a classical manner: lectures, problem solving classes, and lab work. In each of these physics courses the teachers have taken the initative to include small independent project, with a touch of engineering, to enrich the students´ learning experience during the first year in the program, to stimulate their interest in physics and to get them to actually apply the physics they are just learning to real events and tasks.

Table 1. Structure of the program for all students in engineering during the first year. Each course is 6 ects.

First semester All five courses are taken in parallel for 15 weeks	***Second semester*** Four courses are taken in parallel for 12 weeks, ant hen one for 3 weeks
Physics 1: Kinematics and dynamics	Physics 2: Electromagnetism
Mathematics 1	Mathematics 2
Chemistry	Linear algebra
Programming 1	Entreprenourship
Molecular and cell biology	Course depending on student´s chosen field

In the recent past at RU there has been little emphasis on directly introducing engineering during the first year in these programs, except that we initiated the Disaster week three years ago. Disaster week is a 3 day event were students are introduced to some unexpected (simulated) disaster event and are expected to tackle it (Saemundsdottir et al., 2012). For the first time (2011) it was a volcanic eruption close to Reykjavik, the second time (2012) Iceland was in quarantine due to world wide contagious epidemic and in the last one (2013) Iceland had to hold a major European musical event, called Eurovision. All of these events were sudden and overwhelming so the students had to react quickly and come up with realistic plans. Disaster week is a short event, but the main purpose is to break up the long 15 week semester, improve social interaction and comradeship in study and some engineering. Another purpose is to train them in communication: after the event the students have to make public presentations of their emergency plan, their analyses done during the event, etc., such that all students can learn from each other.

Although there is little engineering in the first year in the program, engineering becomes more prevalent during the second and mostly during their third year of the BSc-program.

Although these students aim to become engineers after 5 years of study (BSc and MSc) the larger fraction of them have no formal training in technology when entering the program. Most of the students have completed secondary high school, and only a few have vocational training of some sort. Some of them may have have achieved some technical training during various summer jobs. However, in general, physics is a weak point in their education and therefore we put a lot of didactical effort into that.

PROJECTS IN THE PHYSICS COURSES

Until now, our students in engineering have received their first introduction to engineering in their physics courses in the first year in their study at RU. We teach the introductory courses in a traditional manner, using lectures, demonstrations and problem solving classes, along with regular lab work. We use standard international textbook (Young, Freedman and Ford, 2012). In these courses we try to encourage the students to be „not hesitant“ to apply the physics thay are learning to analyze their ordinary environment, by frequently constructing simple models in lectures (open discussions) covering some topics they may encounter everyday, and open their eyes to the fact that they can do plenty of things using what appears as basic physics (see for example Audunsson and Manolescu, 2010).

Physics 1 – independent lab

During the first semester students take Physics 1, covering traditional kinematics and dynamics. Part of the course are three regular labs were students get well structured instructions on what to do and advise on how to analyse the data and construct the lab report. Currently these labs are collision on an inclined plane, thermal expansion and mechanical resonance. In the fourth „lab“ the students are left on their own to design and implement the last experiment, applying what they have learned in the first three labs. The assignment is to conceive, design and perform an experiment and analyse there result in a manner similar to what they did in the three lab sessions, and the experiment has to do with dynamics and be analysed using the theory they are just learning. Typically, most students are excited, albeit ambivalent, confronted with the freedom to do what they like, but at the same time compelled to use the physics they are just learning. In all the labs two students normally work together as a team, and most of them tend to stay together for other courses as well.

Most of the students are motivated for this type of project, getting an opportinity to decide for themselves what to do. We inform the students at the beginning of the semester that the last „lab“ is of this type, so some of them have decided early on what they want to do, but some are undecided until the last minute. The students can perform the experiment wherever they want, at home, indoors or outdoors, and they may use the facilities at school, including the physics lab. We encourage them to use modern common gadgets like cameras or cell phones as scientific instruments and to do measurements using various „apps“. We encourage them to use video, thereby being able to analyse a fast event or to facilitate the quantifcation of parameters, f.ex. in a collision. Also, part of the reimbursement is to have their video placed on the course Intranet, and some groups place their video on YouTube. It is apparent, that many of the students are having fun, as some of these videos are quite entertaining. The project is completed by turning in a report, often including a CD with video. These projects are expected to be equivalent to one or two days work in total.

There is a tendency of a subset of students to do only trivial experiment, on a rush, like measuring the gravity acceleration from a simple free fall analysis. After observing this tendency we made our demands more specific and we put more emphasize on creativity, originality, and ambition. If students select a simple experiment like that we tell them that to get a decent grade, it has to involve something more demanding or innovative, including drag forces, or be very accurate and include good error analysis. Observing oscillations of physical pendulums and explain the frequency according to theory is common. Analysing the path of a projectile, f.ex. of a ball or a human body jumping off a pier, by using video is also common. Some projects may include conservation of angular momentum of a dancer or a person on a rotating platform. The stopping distance of a car in snow or of a bike or a sled can be fun. Two students analyzed the long jumping of a pet frog. Oher students built a potato cannon, and so on. Although some of these projects may appear simple, they can be demanding on the students because too often they are used to textbook-type-of-problems were they do not have to set up the proplem nor find out what parameters are relevant, let alone measure them themselves. And at the same time apply the physics they have or are just learning. However the practical projects need to be supported by a solid theoretical and intuitive understanding of the basics in order to generate the freedom of thinking.

In doing these projects the students have to conceive the experiment and design it such that fulfills the requirements fram physical theory and reality, and then actually performing the experiment according to plan – often this turns out to be an iterative process. Generally, the student like this, the project is their own idea, it is a process involving both theory and the practice of implementing the idea. Also, many like to include some entertaining aspect in the project, giving them some advantage when they brag about their own project. We expect that this endeavour encourages them to be more willing to apply some basic physics to simple realistic situations, something that engineers have to be trained to do. Although the projects can become involved, we try to keep the demands realistic because this project may take only a limited time. Unavoidable, like everywhere, we have a mixture of students, some of them not too interested in their studies. They may be late with their assignements, or they may try to minimize the effort, mimic simple projects, creating sloppy reports, etc. A challange for us, teachers, is to still give them some reasonable attention, while concentrating more on the good ones. Through the practical projects we often see weak students improving.

Physics 2 – constructing a device

In the second course, Physics 2, we introduce electromagnetism. Three regular labs are part of this course, each one well predefined, but there is some flexibility in analyzing the data and presenting it. As before, two students work as a team and turn in a joint report for each lab. These three labs cover simple DC circuits, magnetic field in coils and RLC-circuit. In this course the final „lab“ is to actually construct a simple device from scratch and based on the electromagnetism they are just learning, present the working device and explain from first principles how it works.

Ingenuity and good workmanship are part of the assignment. When the course starts we tell them that the fourth „lab“ is to construct a working device, but we do not tell them until the latter part of the course what kind of device it is. The assignments have included a) an electrical motor, b) dynamo, c) AC-DC converter, from a battery to flickering lightbulb, d) a calibrated amper-meter, e) a stepper motor and f) loudspeaker. Normally we include some specifications on the device, f.ex. that the dynamo should run from „green“ sources like wind or stream (not turned or shaken by hand), how accurate the amper-meter should be, and how fast the stepper motor should be able to run.

This is challenging for the students, as they have to design the device, construct it, and often the tough part is to get it to work, to actually operate it according to specifications. This is a small engineering task. Some of these devices can be copied from something similar on the internet, but even so, the students have to build it and get it to work. Many students are eager to construct something atypical and original, sometimes it works and it can be quite entertaining. But also, some students try to mimic something they find on the internet in the easiest way.

There are no reports, but instead the students have to bring in the working device, explain to the teachers how it works based on the electromagnetism they have just learned. We pay attention to the workmanship, i.e. they should use screws, bolts and nuts, not tape or glue unless necessary, do soldering if needed, and the device should be able to tolerate transport. Normally there are two teachers that evaluate the device and explanations, allocationg about 5-10 minutes to each project. The best devices are put on a long term display in glass cabinets at the entrance hall of the university. We also encourage them to make video of the process and of the device in action, and these are often placed on the schools web or they post it on YouTube or similar.

By far most students put great effort in these devices, and it is the first time for many of them that they actually construct something technical at school. Some of them even never used a drilling machine before. Many students do this work in the school labs, over the days and nights before the deadline, where they can use some tools or instruments. But most importantly in this case they work in larger groups, learning from each other and comparing different device models that they build and test. These interactive working groups attract those students who are initially clueless to learn from those who have already some practical experience.

They are usually proud of their product and want to show it at school and among friends, and we sometimes get the impression that they are even a little surprised that they could actually construct such a device. Students that may not be very strong in theory may have good insight into how to construct the device and may therefore be the leading persons in the project. We hope that the students also realize that hands on experience and ability to construct can be as important as solving theoretical problems.

Physics 3 – independent lab

Physics 3 is scheduled as a third year course and is mandatory only for students in biomedical engineering, although students in other fields may take it as an elective. In this course we cover optics and modern physics, and more and less cover the rest of the textbook used in the other physics courses, Physics 1 and 2 (Young, Freedman and Ford, 2012). Recently students began asking for projects in this course similar to what they had done during their first year in physics, so last fall (fall 2013) we decided to have one of the labs as an independent project, but the other four labs are more or less standard labs, similar methodology as in the previous courses. The assignment was to quantify how light intensity attenuates with distance (geometric attenuation only), and demonstrate some aspects of polarization of light. The effort by the students should be equivalent to about one full day in total. The assignment was very brief, we listed up some equipment they might use in the lab, and they were allowed to use the facilities at school, i.e. the physics lab. As before, two students should work together and turn in one report. Most of the students performed their experiment in the physics lab, but some did it at home. Students were able to borrow a lux-meter (www.hagner.se) or a simple light meter (www.pasco.com), and some used small solar-cell as a light meter. For light source, some used a small lighbulb, a candle or a laser. The data analysis could be either simple or very involved. Most of the results were as expected, but very often we felt that they could have analyzed the data in much more elaborate manner, including correcting for ambient light, more elaborate functions to fit to the data, take into account near and far fields (i.e. size of the source), and, depending on the meter used, the strength of the light source (possibly as lumens or watts).

Based on the reports we could gauge in what aspects students were performing as expected and where we should intervene and iterate on in class. It is clear from these reports that we need to improve on their skills in analyzing data, something we would not have noticed if they had only performed the standard predetermined labs. In this project we tell the students what to observe and analyse, but they had do design the experiment, using their own ingenuity, finding out what equipment is needed, define the procedure how best to analyse the data, and finally extract the main result of the experiment.

Table 2. Outline of the labs in the introductory physics courses.

Semester	Course	Mandatory labs	Engineering-type of projects
First semester	Physics 1: Kinematics and dynamics	1) Collision on an inclined plane, 2) mechanical resonance and 3) thermal expansion	The fourth „lab“ is to conceive, desgin and perform a project/experiment of students´ own choice. These have included: projectile motion, acceleration due to gravity, braking of bikes and cars, physical pendulums, various other oscillations, frog jumping, using f.ex. video to analyse the dynamics. Students turn in a formal report.
Second semester	Physics 2: Electro-magnetism	1) Simple DC circuit, 2) magnetic field in coils and 3) RLC-circuit.	The fourth „lab“ is to construct from scratch a working device based on electromagnetism. Good workmanship and ingenuity are part of the assignment. The assignments have included a) electrical motor, b) dynamo that extracts energy from green sources like wind and streams, c) AC-DC converter, from a battery to flickering lightbulb, d) calibrated amper-meter and e) loudspeaker. There is no report, just the presentation of the device and explain from first principles how it works.
Fifth semester	Physics 3: Modern physics and optics	1) lenses, 2) nuclear magnetic resonance, 3) diffraction and 4) radioactivity.	The fifth „lab“ is on pre-determined topic, but it is up to the students to design and implement the experiment and analyse the data. This just started, and the first assignment was to quantify how light intensity attenuates with distance (geometric attenuation only), and demonstrate some aspects of polarization of light. Students turn in a formal report.

RESULTS

As discussed above, we have implemented one „independent“ project in all three physics courses we offer our student in engineering. For the two first year courses we have been doing this for several years (Audunsson and Manolescu, 2010). The initial reasons for these projects were 1) to enhance and deepen learning by having the students apply the theory they are just learning to analyze a real dynamic event or process in their everyday setting, 2) break up traditional teaching and offer the students the initative to conceive and design a project on their own, using their ingenuity and interest, and 3) strengthen the idea that they can really apply the theory they are learning in introductory physics to construct an interesting device, that actually operates, which in practice calls for some engineering skills.

Although these projects are small, they are in the spirit of conceive-design-implement-operate (CDIO), and our students in engineering typically like these opportunities to have some initative in learning and realize that it is not enough to know the theory when it comes to solve and construct a real thing. At first, it may not appear rational to introduce some engineering in these courses, but for us the teachers and the students it appeares natural and is easily doable. For several years, these projects have been their first introduction to engineering, and, albeit on a very small scale, in the CDIO spirit. For some type of engineers that we educate, like those in financial engineering, these projects conducted in the general physics courses during the first year are in fact the only technical projects that they do over their three years of study.

Typically, the students like these projects and are proud that they have actually made a working device based on what they have learned in introductory physics courses. Having students conceive and design their own project, although small, exposes were a student performs well and where he is lacking, aiding the teacher in revising his teaching.
The grade for the practical project represents only a small fraction of the final grade for the course. Some students are not happy with that and they are constantly asking for a separate grade that would reflect more realistically the effort and time that they put in the project. That might be justified, but at this moment we are not in favor of a separate grade. Normally the time spent on each project varies between half a day and two days, often covering a full weekend. The allocated time depends on the enthusiasm, abilities and ambition of the students. We usually explain that the real contribution to the final grade is larger due to the increased competence. Instead, to reward their work, we chose to display it in various forms and at various occasions. We normally select five to ten best projects for an exhibition in a dedicated area in the main hall of the University. The exhibition is renewed annually.

Our intention with these projects is to create a link between generic science courses, which are absolutely neccessary for engineering education, and engineering during the first year of study. Generally we feel that the students appreciate these low level engineering projects which pave the way to more advanced engineering courses and projects later in their studies. Although these are low level projects, they turn out to be difficult, but useful, for the students, because for many students this is the first time they have to combine theory and practice in physics. Selection of projects is done in close cooperation with the engineering faculty, and they usually give us good ideas and may sometimes participate in grading.

This inclusion of independent project in each of our three introductory physics courses has been evolving for a few years. As of now, we feel that one project in each course is appropriate. In our opinion, and based on students remarks in courses´ evaluations, these projects stimulate interest in physics, encourages the application of physics to analyse simple events, and last, but not least, provides an opportunity for the students to do some introductory engineering early in their study at the university thereby enriching their learning experience.

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BIBLIOGRAPHICAL INFORMATION

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