Project-based learning in programming courses  
– the effect of self-motivation on learning outcome

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ABSTRACT: We report on project-based learning in a second-year course in Electrical Engineering that comprises a LabVIEW programming course and a basic introduction to data communication and telecommunication. The introduction of open project scope has led to higher student motivation and improved learning outcome. In addition, the inclusion of laboratory exercises that provide further tools for interfacing with external hardware, for example Arduino boards, sensors, and wireless networks, has led to further improvement in project quality as students incorporate in their projects resources from their own interests and from other courses.

1. INTRODUCTION
In this paper we present the use of a combination of lectures, PC-based exercises, laboratory exercises and project-based learning for the teaching of a programming and control engineering subject. The insight presented here is based on the past four years of teaching a second-year course in Electrical Engineering called “PC-based instrumentation and communication networks”. The course comprises learning to program in LabVIEW (Bishop, 2010) – a graphical programming language developed by National Instruments – together with a basic introduction to data communication networks and telecommunications. In the following we give an overview of the course, present the changes we introduced each year of the observation period and describe the effect they had on the students project work and overall learning. We discuss these further and interpret the effect on motivation and learning outcome as well as provide some thoughts for further work.

2. COURSE OVERVIEW
2.1 Course overview – year 1 of observation period
LabVIEW is a graphical programming language that is originally developed as a laboratory control system but has evolved to become a powerful and versatile environment for real-life control systems and industrial applications. The LabVIEW part of the course is taught in a data classroom. Each student has two hours of LabVIEW teaching a week where the teacher introduces new structures and functions in plenum and the students work with exercises on a separate work station each and get assistance when required. In addition, students carry out a series of laboratory exercises in groups of two supervised by an experienced engineer. The last four weeks of term, the students work on a LabVIEW project typically in groups of two. This is presented in further detail below, at the end of this section.

The course comprises also an introduction to data communications and telecommunication. For this part we use weekly lectures in an amphitheatre and include some exercises the students can complete later as voluntary homework. In addition, there are laboratory exercises as for LabVIEW.

The first years the authors taught this course, the data communication part focused primarily on the Applications layer, Transport layer, Network layer and Link layer. In addition, there was a good introduction on standardisation work. The laboratory exercises were in accordance with this focus and included one exercise with a web server and web client and communication using HTTP, one exercise on DHCP server, routing protocols and IP addressing, and one TCP/IP exercise.

TCP/IP communication is also implemented in LabVIEW exercises (Reynders and Wright). In particular, information is exchanged between a server program where a certain operation is carried out and a client program from where the user can both monitor the progress and control the operation of the server.
During the last four weeks of term all lectures and laboratories in the course have been already completed and the students can focus on their project. In previous years as well as during the first year of the four-year period this survey refers to, the students were presented with five different projects to choose from. Several of these included external hardware that is controlled by LabVIEW while two of the proposed projects did not include hardware. With one exception, the projects require a client-server architecture.

All lab exercises need to be completed and the project work needs to be completed and approved in order to be eligible for the final written examination. The written examination includes 50% LabVIEW and 50% data communication exercises. The written exam counts for 70% of the final mark while the marks attained from the project count for the remaining 30%.

2.2 Student evaluation after year 1 of the observation period

Student evaluation at the end of year 1 of the observation period revealed the following. The students were pleased with the LabVIEW part of the course. They appreciated in particular the project work at the end of the course and felt they actually learned LabVIEW during this four-week project period. They thought the labs were good and useful. The data communication part of the course received less enthusiastic comments. Students considered it a “dry” subject they needed to command in order to get good marks, but had relatively low motivation to learn otherwise.

Several of the top students that were the first to complete all LabVIEW exercises at the data class sessions, wished for further exercises and more challenging problems they could work on after class. In addition, several of mainly the same students proposed that project topics were open for the students to define themselves rather than having to choose from given alternatives.

3. CHANGES INTRODUCED IN YEAR 2

3.1 Changes introduced in year 2 of the observation period

In response to the evaluation and proposed modifications by our students, we introduced the following changes. The list of exercises that are given in each of the data class sessions of LabVIEW was enhanced to include several extra exercises the students can work on if they wish to. Standardisation related work was in practice removed from the curriculum with the exception of a short introduction. In its place we introduced to a larger extent Layer 2 and Layer 1 material including wireless and optical networks. The third and most important change that year was that we opened for projects where the scope is defined by the students. The way this is implemented is that the students need to send an email with a short description of the project they wish to carry out – typically one paragraph. They then receive comments and suggestions and get it approved by the teacher prior to project start.

3.2 Student response after year 2 of the observation period

These were well received by our students. The students were still pleased with the LabVIEW part of the course. They appreciated lab work and in particular the project work, like in year 1. The data communication part of the course was still less favoured and the topic was still described as “dry”.

The most marked effect was on the quality of the projects. Here students incorporated external hardware and demonstrated quite advanced projects, among others in areas of their own interest. The overall engagement in project work was significantly higher. This is further discussed in section 5.

4. CHANGES INTRODUCED IN YEAR 3 AND 4

Encouraged by the evaluation and response from our students, we continued on the same line and introduced the following changes in year 3. The web-server related laboratory exercise was replaced by a wireless sensor network that uses Zigbee Xbee and Arduino. LabView is used for sensor data logging and user interface. The curriculum of the data communications part of the course was changed somewhat in that the part on wireless networks was extended. In addition, there was some increased focus on security.
In year 4 of the observation period, we had to drop the Zigbee laboratory exercise as we temporarily lacked a laboratory engineer with the right expertise. At the same time these students had already used Arduino in another course and were quite familiar with it. In addition, we introduced an extra teaching hour each week with data communication exercise solving.

Student evaluation at the end of year 3 of the observation period revealed the following. The students were equally pleased with the LabVIEW part of the course. They appreciated lab work, if with some suggestions for improvements. The students appreciated in particular project work. Some of the comments point towards extended project work. The most marked effect was again on the quality of the projects. Some of the students incorporated external hardware, including Arduino boards and LEGO robots. In addition, a couple of the projects incorporated wireless communication between the external equipment and the LabVIEW control or the Arduino board, etc. Overall, the project quality was improved. This is further discussed in section 5.

The written exams and actual final marks were not conclusively improved. This is discussed in the next section. At the same time, and based on the student evaluation, there has been a gradual improvement of the students own evaluation of their learning outcome. This is summarised in Table 1 below. The number of students that participated in the evaluation is relatively low, so the results are only indicative. Our gradual adjustments of the communications part of the course have led to clear improvements. These do manifest themselves in the results from the written examination (not shown).

<table>
<thead>
<tr>
<th>Observation year</th>
<th>LabVIEW</th>
<th>Datacom</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>20 (20)</td>
<td>10 (20)</td>
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<tr>
<td>2</td>
<td>21 (21)</td>
<td>15 (21)</td>
</tr>
<tr>
<td>3</td>
<td>31 (31)</td>
<td>23 (31)</td>
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<tr>
<td>4</td>
<td>28 (28)</td>
<td>24 (28)</td>
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5. DISCUSSION

The graphical interface of LabVIEW is intuitive and although a rather advanced programming environment can be created based on the LabVIEW platform, the threshold for building a simple control system is relatively low. The graphical interface appears to appeal also to students that are not especially enthusiastic about programming to begin with. These students that may not be particularly inclined to abstraction tasks, seem to be assisted by the visual interface of LabVIEW. The relative ease of getting started and getting to write simple programs, combined with the immediate result via the front panel, apparently lead to an experience of mastery. This in turn apparently provides a positive feedback mechanism that increases self-confidence and encourages the students to continue their efforts and improve their knowledge and skills. Biggs and Tang (2007) underline also the importance of student motivation, expectations of success and alignment with intended learning outcome. In this regard, LabVIEW is a useful tool for attaining relatively good programming skills also for the less gifted/less enthusiastic among students.

The month carrying out project work is clearly a month with very high learning outcome. It is not easy to quantify the level of learning attained by the class and the effect of the changes we made during this four-year study from the written examination. The written examination results are only indicative and difficult to decipher. However, based on our observations from interaction with the class during lectures, exercises and labs, there is little doubt that there has been a considerable improvement after year 1 in this study. The feedback provided by student evaluation, points clearly in the same direction.

The first year of the observation period there were many highly motivated students that appreciated programming to begin with. These students were forced to choose one of the five project models that were available at the time. The students’ creativity was channelled towards adding several finesses in their programs and the overall level of the projects was very high. There was however some frustration over the limited project scope available.

Opening for self-defined projects in year 2 of the observation period made it possible for students to incorporate their own interests into the projects and to make use of resources they had outside the course, for example based on their own interests and hobbies or based on work they had done in other courses.
Examples are a) a project where LabVIEW was used to create an interactive DJ music server that was connected to a professional music system, b) a project where vital data were collected from a set of body sensors and ambient sensors at an (imaginary) patient’s home, analysed, stored, and forwarded together with alarms to doctors and nurses as required, c) a LabVIEW program for the remote control of an actual laboratory water-tank system. The students were proud of their projects and put a lot of additional effort to add all sorts of finesses and extra features. Motivation was clearly higher than the preceding year and the reported experience of “fun” was very high. The general marks attained from the LabVIEW part of the written examination were also improved. We considered this a success. It is also worth noting that not only top students were involved in these self-defined projects. Another important aspect is that the ambition level of these projects is typically significantly higher than the five original project models. These observations have been sustained the subsequent years.

The inclusion of a laboratory exercise with a wireless sensor network and use of Arduino in year 3 of the observation period, has led to what we consider a further improvement of the project work. Several of the projects incorporated control of external hardware and some projects used wireless network communication. Examples are a) a LabVIEW-controlled LEGO robot system for sorting garbage and recirculation, b) an actual alarm system with optical sensors controlled via LabVIEW realised using Arduino, c) a “home-made” toy robot with a series of sensors/actuators on Arduino boards controlled via LabVIEW. In many cases the students exceeded the total number of hours that are required for the project and described again the project as great “fun”. Although the wireless laboratory exercise was not included in year 4 of the observation period, better experience with Arduino in this class had a similar effect on project variety and quality. In total, the students have impressed us with their zest, creativity, and ability to combine available resources and learn by doing.

The effect of project work on learning outcome cannot be emphasised enough. This is in accordance with other studies (Blumenfeld et al., 1991). Biggs and Tang (2007) underline also the importance of student motivation, expectations of success and alignment of teaching methods with intended learning outcome.

In our experience, project work has been the highlight of the whole course. In fact, several of the students have perceived project work as a sort of reward for their learning efforts throughout term. This has been the case especially after we introduced open project scope for the projects in this course.

6. CONCLUSION AND FURTHER WORK

The changes introduced during the four years presented here show in our opinion an encouraging improvement of learning zest and learning outcome. In collaboration with the lecturers of other courses, e.g. electronics and C-language programming, some of which are taught in parallel and some of which are taught prior to the course presented here, we intend to introduce further tools that can be potentially introduced in the projects of our course. These include external data acquisition kits owned by each student, introduction of Arduino programming – and corresponding projects – together with electronics classes, and more. These will hopefully create further synergies between the courses through our curriculum, increase the quality of the studies and of the overall learning outcome.

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REFERENCES


