TEACHING PROJECT COURSES IN LARGE SCALE USING INDUSTRY LIKE METHODS – EXPERIENCES AFTER TEN YEARS

Tomas Svensson, Svante Gunnarsson

Linköping University, Sweden

ABSTRACT

A Design-Build-Test (DBT) project course in electronics is presented. The course was developed during the first years of the CDIO Initiative, and it has been given successfully for almost ten years within two engineering programs at Linköping University. More than 2000 students have passed the course, and it is considered to be one of the most popular and also demanding courses within these programs. The key factors that have contributed to the success of the course are:

- Clearly defined learning outcomes.
- A suitable and well working course organization.
- A systematic method for project management.
- Challenging project tasks of sufficient complexity.
- Laboratory workspaces with modern equipment and high availability.

The aim of the paper is to describe these key factors in more detail based on the experiences that have been gained during the almost ten years the course has been given.

KEYWORDS

Project course, electronics, project management model, assessment.

INTRODUCTION

Linköping University was one of the four original collaborators of the CDIO Initiative [1,2]. During the first years of the CDIO Initiative the main efforts were spent on redesign of the Applied Physics and Electrical Engineering program, and a summary of the outcomes of the redesign can be found in [3] and [4]. One of the main results of the redesign was that a sequence of DBT-courses was introduced into the program. One aim of these courses is to cover sections two, three, and four in the CDIO Syllabus, see [5], which means emphasizing personal skills, interpersonal skills, including team work and communication, and skills in development and implementation of products and systems. An introductory course was introduced in the first year, the DBT-course in electronics, which is the main topic of this paper, is given during in year three, and finally there is a set of DBT-courses during year four and five, related to the specializations of the program.

Project-based learning in general has been studied by many authors, and a number of interesting contributions can be found within electrical engineering, and e.g. in [6] the authors discuss project-based lab teaching in power electronics. The paper contains a brief discussion of project-based learning in general, but the emphasis is put on the technical details of the project tasks. In [7] the authors deal with project-based learning within embedded system design, where the task is to design a line-following robot. The main part of the paper deals with technical aspects of the project task, but it is also discussed how competitions are used to motivate the students for the design task. In [8] the authors put substantial emphasis on project management, and discuss issues like how to break down a project task into sub-tasks, formulation of system requirements, and the importance of a following design flow.

Compared to previous publications dealing with project-based learning the key points of this paper are that the DBT-course in electronics is based on the CDIO framework, that the project tasks are handled using an industry like model for project management, and that the course has been run successfully in large scale for almost one decade.

The main questions that will be answered in the paper are:

- How can a course of this type and volume, with sometimes up to 120 students, be organized and managed?
- How can a project management model, in this case the LIPS model, support the execution of the project and the assessment of the student learning?
- How should the workspaces be organized, equipped, and made available for the students?
- Which types of project tasks are suitable in order to enable for the students to reach the goals, and have fun at the same time?
- Which types of evidences indicate that the design, implementation, and execution of the course have been successful and contributed in a positive way to the overall quality of the engineering education?

LEARNING OUTCOMES BASED ON THE CDIO SYLLABUS

The CDIO framework is based on two fundamental documents, the CDIO Syllabus [5] and the CDIO Standards [9] respectively. The first document, the CDIO Syllabus, can be seen as a specification of the desired knowledge and skills of a graduating engineer, and it is structured in four main sections:

1. Technical knowledge and reasoning
2. Personal and professional skills and attributes
3. Interpersonal skills: Teamwork and communication
4. Conceiving, designing, implementing and operating systems in the enterprise and societal context.

Using the CDIO Syllabus as reference the main points of the learning outcomes of the course can be summarized as follows. The students should be able to:

- Integrate knowledge acquired in previous courses by designing and building a computer controlled device. (Section 1 of the CDIO Syllabus [3]).
- Use a structured tool for project management extensively, including to write and follow-up project and time plans and other relevant documents. (Sections 4.3-4.6)
- Participate in engineering teamwork in an industry like context, and to actively contribute to a well functioning project group (Section 3.1)

- Practice various engineering skills, such as measurement technology, trouble shooting, system thinking, structured design, modern development tools etc. (E.g. Sections 1.2-1.3,2.1-2.3)
- Present project results orally and in written documentation. (Section 3.2)
- Model digital systems using the hardware description language (VHDL) (Section 1.3)

In the sections below it will be described how the course is designed in order to enable for the students to be able to reach these goals.

COURSE ORGANIZATION

During the course the students are organized in groups of six students. Over the years the number of groups has varied between approximately 10 and 25 each time the course has been given. The organization around each project group is illustrated in Figure 1. I each group there are a number of specified roles, including project manager, persons responsible for documentation, hardware design, software design, testing, etc. The roles in the group are appointed by the project members themselves. All projects are ordered by a project sponsor. Each project group has a supervisor and access to a number of technical experts. In a course with 20 groups there are 3-4 sponsors, and one of them is the examiner of the course. In order to be able to establish good contacts with the groups and to be able to review documents within reasonable time limits it is not realistic to have more than 5-6 groups per sponsor. The collective efforts of the sponsors correspond to at least one full time faculty member. There are also 5-6 supervisors, normally technical staff, corresponding to approximately one and a half full time staff member. In addition, there are about ten technical experts available contributing with a few hours of consultation per expert over the entire course.

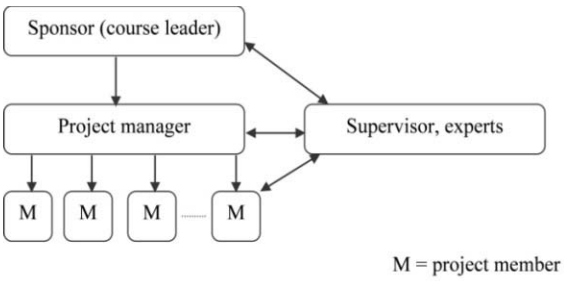

Fig. 1. Organization of project groups.

The course corresponds to 8 ECTS credits (one year corresponds to 60 ECTS credits), and it runs over an entire semester. The first half of the semester is used for establishing the group, planning the project and for a preliminary design of the product. There are lectures about the project model and its documents, hardware description language (VHDL), processors, sensors, etc. There are also laboratory exercises to be performed by each group. These exercises prepare the students for the work in the project. This part also involves a lot of discussions and negotiations between the group and the project sponsor. The second half of the semester is devoted to the execution part of the project. Now the students have 24 hour access to the workspace, see below, and they do all the tasks that lead to the project result. The sponsors and the supervisors have weekly meetings during the execution part. Here the time- and status reports are studied to reveal problems in the projects or in the project groups.

THE LIPS PROJECT MODEL

Introduction

LIPS (Linköping Project Management Model) is a tool for project management, and it is designed according to modern industrial project models and adapted for use in education or in small industry projects. A thorough documentation of the model is given in [10]. The tasks described in the model are used for managing the work toward the predefined goals and for facilitating control of the work. The model introduces the phases, definitions and decision flow needed for running a project in an efficient way. The three phases of the model describe the project preparation and planning, the project execution and the project delivery and evaluation phase. see Figure 2.

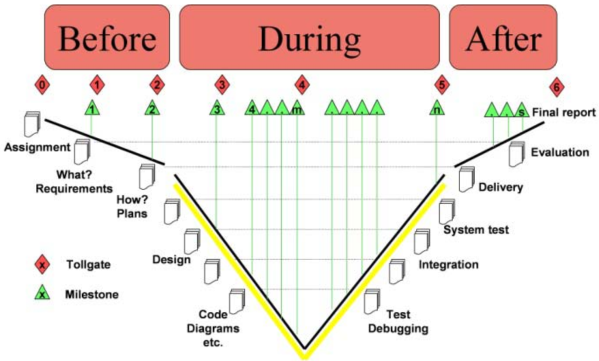

Figure 1. The LIPS Project Model

The different project documents are described and exemplified by electronic templates. The aim is to decrease the time to produce and review the documents. Examples of documents are requirement specification, project plan, time plan, status report, meeting minutes, and project reflection document. The use of milestones and tollgates is introduced. At defined tollgates the group is required to deliver documents etc. to get approval for entering the next phase in the project. The dynamics in a project is trained by the use of a sponsor- executer relation. The model is scalable and can be applied to project-based courses with differing levels of complexity.

The Before Phase

A project is initiated by an idea or a need, which is defined in a *project directive*, see Figure 3.

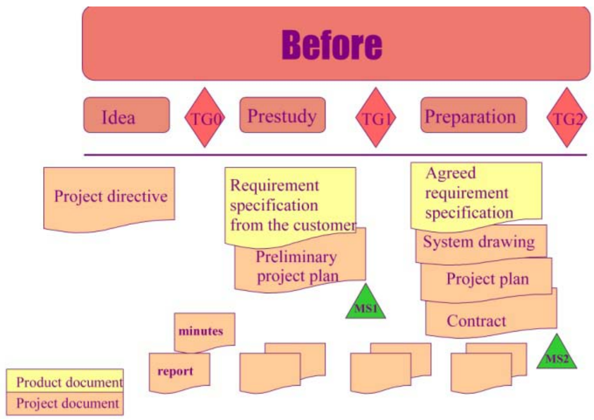

Figure 3. The Before phase

This is the first document in the before-phase, and the aim of the before-phase is to investigate what the group is going to do, and how it is going to do it. If satisfied with the project directive, the sponsor will at tollgate 0 (TG0) task the project manager with conducting a pre-study. During the pre-study the project directive is translated into more concrete demands for what should be done; this is known as the *requirement specification*. It includes functional requirements as well as requirements of performance, economy, delivery, documentation etc. A preliminary estimation of costs, resources and time is also made. This can result in a short preliminary version of the project plan. The result of the pre-study is delivered to the sponsor, who will decide if the project is allowed to continue (TG1). During the preparation process, the requirements are studied and a description of how to execute the project task is documented in a system drawing.

The next task is the preparation of a detailed *project plan*. Within the plan, the project organization and phases are described and all activities are identified and their duration is estimated. The project plan will define how often meetings are to be held, and how often status reports are to be given to the sponsor. It must include a *resource plan* and a *time plan*, and in some cases a *quality plan* and a *test plan* are also included. The time plan is a detailed description of when each activity is to be executed. It shows dependencies between activities as well as the duration of each activity. When necessary, a system test specification is created. The project has now reached milestone 2 (MS2). The specifications and plans are delivered to the sponsor, who will decide if the execution phase of the project can proceed (TG2).

The During Phase

Activities performed within the during-phase lead to the project results. Depending on the work model in use, different documents and activities will be executed. The During phase is illustrated in Figure 4.

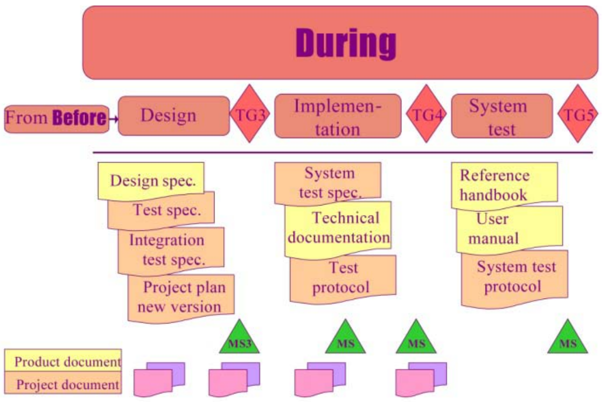

Figure 4. The During phase

A number of milestones are required during the execution phase, since this phase often has a significant duration. Unforeseen problems will almost certainly arise during the execution phase and the ability to rapidly handle deviations is of the utmost importance to the success of the project. A new tollgate, TG3, is appropriate when the project has reached a state where an accurate estimation of the timescale can be made. In a constructional project this point is reached when the *design specifications* are ready, MS3. At this stage it may be necessary to review the project plan. Also, there is often a further tollgate during the test phase, TG4, at which the sponsor reviews the interim results. The execution phase is completed with a tollgate, TG5, at which a decision is made on the suitability of the results and if the final phase of the project can commence.

The After Phase

During the after-phase, the project outcome is transferred to the sponsor, and the project is closed, see Figure 5.

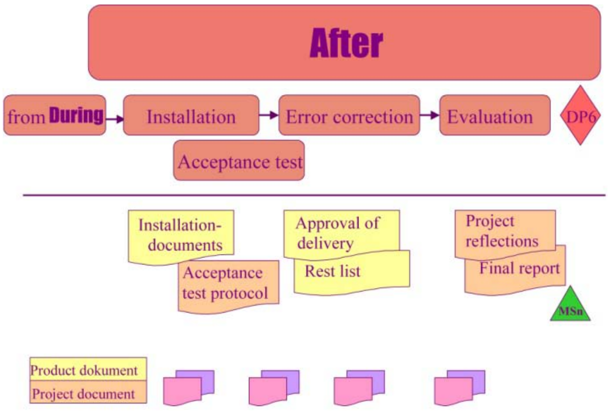

Figure 5. The After phase

The after-phase may include installation at the customer site of the finished product. After installation the customer will conduct an acceptance test. Comments from the customer are documented in a rest list, which is often handled in a separate clean-up project. Other tasks to be conducted in this phase include education of the customer´s staff and project evaluation. The project evaluation is documented in a *reflection document*.

EXECUTION OF THE PROJECT WITHIN THE DBT-COURSE

The Before Phase

The starting point for the project work is a project directive written by the sponsor. This includes a description of a project task, the delivery date and the number of hours allowed to be used. The project task has to be defined carefully by the course management. It is important that the design can be divided into a couple of modules to give the basis for a good project work. The task also needs to be scalable in order to handle skilled and less skilled project groups.

After having formed the project group and selected a project task, the next step is to write a requirement specification. This document must be negotiated with the sponsor. Requirements are given different priorities. All requirements and goals must be measurable in order to verify that the product is correct upon delivery. This is an experience that is very useful, for example when initiating a final year project. When the sponsor has approved the document at tollgate 1, often after several iterations, the project enters the preparation phase.

The group now makes a system drawing which includes a preliminary design. This design is then used to find work activities. The ability to identify work activities in a complex task is important!

The work activities are needed when writing the project plan and the time plan. The duration of the activities and the dependences between activities must be considered, as the activities must be arranged in such a way that the calendar time is minimized, and that the utilization of resources is optimized. Other important parts of the project plan are terms for cooperation, definition of roles and responsibilities, a document plan and a plan for reports and meetings.

The preparation phase is concluded by a TG2 meeting. The sponsor asks questions such as how the work activities have been found, how the time estimation has been done, and if all students in the group accept the plan and the terms of cooperation. The plan is checked so that no important activities are missing and that resources are used effectively. The students are asked if they, with their current planning, would be willing to take the risk to finance the project with their own money. At the end of the meeting the plans are signed by all project members and the sponsor signs the tollgate protocol.

The During Phase

Now the execution of the project starts. The first step for the group is to produce a more detailed description of the design, including both hardware and software such as flowcharts and circuit diagrams. The design specification must be discussed and approved by the supervisor (TG3). At this stage the students must also review the project plan. After approval the group is given access to the project lab Muxen, see Section VII. During the execution phase activities such as coding, soldering, testing, integration, system testing, etc. are executed. The students must do individual time reporting once a week. The group will be warned if too little (or too much) time is used by the group or by individuals in the group. The sponsor will also ask for status reports, where the group has to report about finalized activities, problems, changed planning etc. The sponsors and the supervisors meet once a week to discuss the progress of each group. At the end of the execution phase, the assessment of the technical contents is done. The sponsor checks that the project outcome fulfils the requirement specification (TG5). If this is approved the group is allowed to deliver.

The After Phase

The delivery is done by presenting the project outcome at a small conference and to demonstrate the result. There is often a competition between the delivered products.

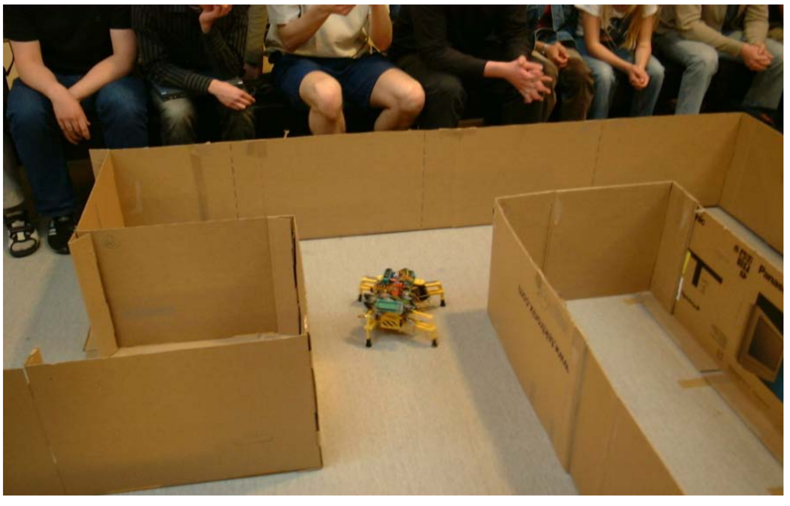

Figure 6. Competition for four-legged robots.

The result must also be described in a technical documentation. After the delivery has been accepted the group writes, a reflection document.

Assessment of Engineering Skills

The well-defined steps in the project management model automatically introduce continuous assessment of the engineering skills. Using the project model one can clearly differ between the assessment of the process and the assessment of the practical result of the project. There are a large number of aspects of team- and project-based courses that can be assessed. The list below shows some of the aspects that can be assessed using the project model. The assessment must be continuous and the tollgates can be used as trigger points.

Planning: How is the planning done? Is there enough time planned for the different steps? Has the planning been checked lately? Are there planned test activities?

Design process: Is there a good system design before going into details? Is the design innovative? Does the process include several design generations?

Resource management: Has the planning been changed due to new conditions? Is the workload spread out in the group? Has the group and the individuals spent the planned time on the activities? Do the time reports match the planning? How did the group adapt to detected problems?

Communication: How did the communication between the project members take place? How was the communication between the group and the sponsor?

Documentation: Are project documents delivered on schedule? What is the quality of the documents? Has the group reviewed the documents? How many versions are there before an accepted version is available? Is there a good documentation of the project outcome? Are there test protocols?

Technical result: Is the project outcome accepted and checked against the requirement specification?

Reflection: Has the students analyzed the process in a reflection document? What is the quality of the discussion in this document?

PROJECT TASKS

Each project group designs and builds a digital system controlled by at least three microprocessors. The design includes several types of data buses, several sensors, blue tooth communication for sensor monitoring, and parameter initialization. The task includes construction of both hardware and software. Example of projects are autonomous walking robots, with the task to find their way through a labyrinth, robots that can be sent into an unknown environment and produce and send a map to a remote computer, rescue robots, see Figure 7, with the mission to fetch an item in a labyrinth and bring it back.

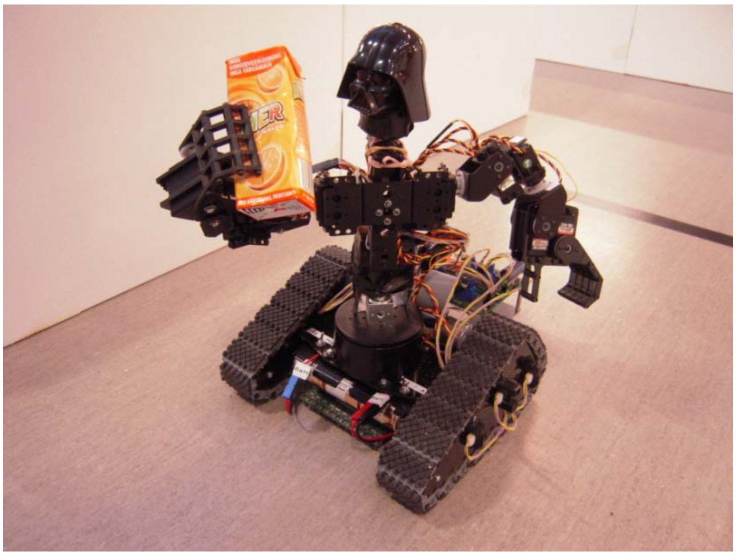

Figure 7. Rescue robot.

During the project the students must learn to use several design tools. Digital circuits such as CPLDs (Complex programmable logic device) are often used and thereby tools for hardware programming and simulation by use of VHDL must be used. Tools are needed for programming of micro-controllers both in C-language and in assembler. In-circuit emulation is used to debug the real time programs. Wiring techniques are used to connect the circuits in the design and advanced logic analyzers are used for finding errors. Each project group is offered a portable computer with administration tools, design tools, LIPS templates etc.

THE MUXEN LABORATORY WORKSPACE

Muxen is a laboratory workspace for projects in electrical engineering at Linköping University. Muxen consists of four laboratories, a common area with a discussion corner, a conference room, a component room and a server room. The size of the laboratory is about 450 m2. Each of the four laboratories includes 16 lab benches equipped with a PC and advanced measurement instruments such as logic analyzers, oscilloscopes, etc. Each of the 64 lab benches is during one semester “owned" by a project group of up to 6 students. This gives that Muxen can serve up to 384 students simultaneously! Access to Muxen is controlled by a magnetic card reader, and the students have 24 hour access. One research engineer is employed for IT support, service and maintenance; and six to seven staff members are involved in supervising the project groups. The structure with four laboratories connected to a common area is very flexible. Several different courses can use Muxen at the same time. As an example, during spring semester, two of the laboratories are used for projects in advanced logical design (150 students in 40 design groups) and two of the laboratories are used for projects in design of computer controlled robots (140 students in 24 project groups).

Figure 8. Views over project work inside the workspace Muxen.

EVALUATION

Like all courses within the engineering programs at Linköping University the course is evaluated by the students using a web based evaluation system. Table I shows the overall grade for the project-based course in electronics for the years 2004 – 2011. The course is rated using a scale from one to five, where five is highest, and as can be seen the grades are very high.

TABLE 1
OVERALL GRADE FOR THE PROJECT COURSE GIVEN FOR THE APPLIED PHYSICS AND ELECTRICAL ENGINEERING PROGRAM

Year	2004	2005	2006	2007	2008	2009	2010	2011
Grade	4.39	4.41	4.25	4.54	4.61	4.32	4.58	4.45

In addition, in 2007 the Applied physics and electrical engineering program received the award “Engineering Program of the Year" by the Association of Swedish Engineering Industries. The motivation of the award explicitly mentions the CDIO framework, the project-based courses and the use of the LIPS model for project management as an excellent basis for an engineering career in industry. Furthermore, as mentioned in the Introduction the electronics project course is the second step in a sequence of three project courses in the program. It has turned out to be very valuable to use a common structure for the execution of these courses since it has also had a positive impact on the execution master’s thesis. This is illustrated in [11], which presents an analysis of a large number of reflection documents written in connection with the master’s thesis.

SUMMARY AND CONCLUSIONS

A project-based course in electronics has been presented. The course has been given in large scale, approximately 75 - 150 students each time, twice a year for almost ten years. The key factors that have contributed to the success of the course are:

- Clearly defined learning outcomes.
- A suitable and well working course organization.
- A systematic method for project management.
- Challenging project tasks of sufficient complexity.
- Laboratory workspaces with modern equipment and high availability.

The course is one of the most popular one in both of the engineering programs where it is included, and the course and the project management model is appreciated by industry.

ACKNOWLEDGEMENTS

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Biographical Information

Tomas Svensson is an Associate Professor in Computer Engineering at Linköping University. He his responsible for various courses in Computer Engineering and in particular the Project Course in Electronics. He is also one of the developers of the project model LIPS. He is MSc in Applied Physics and Electrical Engineering from Linköping University.

Svante Gunnarsson is Professor in Automatic Control and Chairman of the Program Board for Electrical Engineering, Physics and Mathematics at Linköping University, Sweden. His main research interests are modeling, system identification, and control in robotics. He served as Chair of the Organizing Committee of the 2nd International CDIO Conference 2006.

Corresponding author

Prof. Svante Gunnarsson
Department of Electrical Engineering
Linköping University
SE-58183 Linköping
Sweden
svante@isy.liu.se