DEVELOPMENT OF A MULTIDISCIPLINARY DESIGN-BUILD-TEST PROJECT COURSE

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Abstract

Design-build experience, which is one of the CDIO standards, is a central experience when learning the process of developing new products and systems. We describe the development of a multi-disciplinary DBT course, which comprises both an industrial relevant student project and non-technical exercises like project management, teamwork (team dynamics) and communication. The goal is to create a learning environment where students from different study program worked together in projects resembling the conditions for project work in the industry. We believe that this approach will promote valuable skills in the field of product and system development which is important for the students' future role as engineers.

Keywords: Design-Build-Test, multidisciplinary project course, engineering education

1. Introduction

In 2006, a CDIO project was initiated at the faculty of technical and natural science at Umeå University, Sweden. Six study programs participate in this project, of which the main goal is to implement the CDIO standards into the education. As a central part of the project we developed a multidisciplinary Design-Build-Test project course (15 ECTS) where students from different study program participated in the same project. The course was introduced late in the study program (3rd year for the Bachelor of Science (BS) program student and 4th year for the Master of Science (MS) program students). We wanted the students to have achieved a considerable technical knowledge within their own discipline, e.g. biotechnology, computer science and engineering, engineering physics, applied electronics engineering and mechanical engineering. This was to ensure that more advanced project could be run that also were of interest for the industry. Since the Bachelor of Science program is more focused on applied engineering than Master of Science we reasoned that these students have earlier reached a more "focused engineering mind" compared to the MS students.

Two different projects were run, one focused to design, implement and test a demonstrator system for intelligent control of a hydraulically actuated crane with a gripper ("crane-project"). The other project ("biotech-project") aimed to develop a test system with high capacity to analyze the effect of low molecular weight chemical compounds on bacterial motility.

The examination was based on three components: i) written individual report analyzing the project process in terms of self evaluation and assessment of their own practical work. ii) the project-group's oral evaluation of the project process. iii) the level of activity during realization of the project. iv) the final project report and other documentation

2. Pre-course planning

The student should encounter a Design-Build experience to learn the process to develop new products and systems in a multidisciplinary environment.[1-3] To achieve this two key elements were identified i) involvement of interested and devoted teachers, and ii) relevant projects that are multidisciplinary and for a successful outcome requires deep knowledge of different subjects that only can be achieved by creating project groups that involves students from different study program.

A two day teacher residential course was held six months ahead of the project start to discuss management and contents of the projects and to facilitate the teachers team-building. The LIPS project model was designed at Linköping University to support the CDIO concept [4]. The LIPS model introduces a professional project management approach into the academic environment. The model introduces the phases, definitions and tollgates necessary for running a project in an efficient way. In addition, all documents needed to run the project model was made accessible for us through collaboration with our colleagues in Linköping. Different project plans was discussed and emphasis were put on the importance of assessable and accurate aims, i.e. it should be easy to determine whether the aims of the project were obtained (what should the project deliver). E.g. in the Biotech-project (see below) a quantitative requirement was added in the project directive to make the project more challenging.

3. Learning outcome

In addition to train design and build experience, also objectives like formalized project planning/management, administration/documentation, personal communication and oral/written presentation, and to make an overall responsible contribution as a member of a team are all important features to be learned. The learning outcomes of the course were the following:

- apply engineering skills and knowledge and participate in the entire developing process of a product or a system
- plan and organize the work in a developing project
- actively participate in a project group and understand the roles for each of the different group members
- apply engineering reasoning and creativity
- practice oral and written communication, both within the project group and externally
- establish and follow a project plan for a defined project
- evaluate the product/system with respect to a sustainable- and a commercial life cycle assessment perspective
- demonstrate the results from a large project both in written form and orally.

4. Contents of the course

The course (15 ECTS) was run at 50% study tempo over the entire fall semester (from September 2007 until the middle of January 2008). All together 22 students from 5 different study program participated in the course. The course started, for all students, with introductory lectures in project management (LIPS project model), communication, group dynamics, and team building. In addition, specific lectures for the crane-group and the biotech-groups, respectively, were performed to give an adequate background.

The projects were managed using the LIPS project model.[4] During the "*Before phase*" (four weeks) the commission was given and the project was planned by the project students. The projects groups received a customer-defined rather unspecific task. After discussion with the customer the task was defined in a *requirement specification* and a possible realization was outlined in a *system drawing*. The plans for the execution of the project were described in a project plan.

After decision by the customer, the execution of the project was allowed to be started. At this point the so called "*During phase*" began where the practical project work was carried out. This phase lasted for about 10 weeks and was concluded by the *system test* where the project outcome was demonstrated for the customer and the industrial partner. During the "*After phase*" the project result was transferred to the customer and at the end the project was closed. Finally, at the very end of the course, an evaluation of the project was made including both the project process and the technical outcome.

5. Short description of the projects

Two different cross-disciplinary projects were run. The first one (denoted as the crane-project) had the overall goal to design, implement and test a demonstrator system for intelligent control of a hydraulically actuated crane with a gripper. The second project (denoted the Biotech-project) was in the field of biotechnology, and aimed to develop a test system with high capacity to analyze the effect of low molecular weight chemical compounds on bacterial motility.

5.1 The crane project

The project customer was IFOR (acronym for Intelligent Off-Road Vehicle), which is a research center established in collaboration between Umeå University and a network of industrial partners involved in the development of automated forestry machines. The companies active in the customer group were Komatsu Forest, Optronic and Indexator. The purpose of the demonstrator system for "intelligent crane control" was to develop and demonstrate an automated crane-control system that could serve as an example of a technical solution which would stimulate the industry to progress the technology further.

The automated system should have the ability to move a tree log between two given positions while avoiding obstacles. An overview of the system is given in Fig. 1.

- The Motion Planning subsystem should generate the optimal path of the crane motion between two points in space with respect to speed, security, and energy consumption. Known obstacles should be avoided.

- The Motion Control subsystem should receive crane data and control the movement of each link of the crane according to the desired motion defined by the Motion Planning subsystem.

- Sensors should be used for detection of obstacles around the crane and for measuring the position and motion of the crane and the gripper.

It is clear that deep knowledge in the disciplines engineering physics, mechanics, electronics and computer science is required to develop the different subsystems. Particular challenges were rigid body dynamics and inverse kinematics, path planning and optimization, design and implement controllers in Simulink environment, understanding of friction and hydraulics in mechanical systems, image and signal processing, practical construction of sensor devices and signal paths. For integration of the components knowledge in system design was needed.

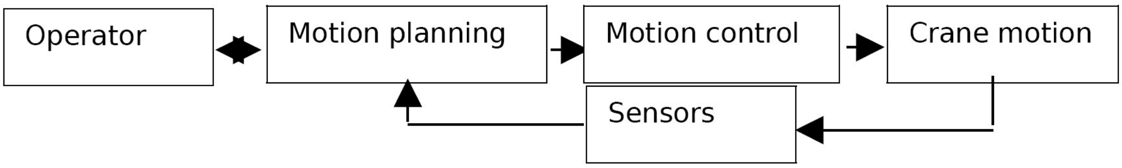

Fig. 1 Overview of the system

The project team succeeded to combine and develop the Motion Planning and Motion Control parts, whereas the goals for the Sensor Objects were not reached, since no human or obstacle detection got fully implemented and integrated in the system. The results were restricted to a system capable to automatically control a four meters crane with a log in the gripper to plan and execute a motion from one point to another, avoiding known obstacles.

5.2 The Biotech-project.

The project customers were research groups at Umeå University and Innate Pharmaceuticals AB. A library containing approximately 30000 different low molecular weight chemical substances has previously been screened for substances that inhibit the type III secretion system of bacteria. From this screen, substances have been identified that now are lead compounds in the search for alternatives to antibiotics to combat bacterial infections. A small pharmaceutical company (Innate Pharmaceuticals AB) has emerged from this research and is now developing these anti-infective agents for clinical use.

The biotech-project aimed to develop a test system with high capacity to analyze the effect of low molecular weight chemical compounds on bacterial motility. The system should be able to analyze 100 substances per hour. Preferable 4000 substances should be screened in the study.
The biotech project was run in two parallel project groups both consisted of 7 students from 3 or 4 different study program.

In summary the students should solve the following problems:

1) To determine which bacterial strain to be used in the studies.
2) Find/develop appropriate methods to cultivate the bacteria in the presence of the substance.

3) Find/develop methods to detect bacterial motility.
4) Analysis of the results
5) Find a method to detect false positive results (to discriminate between substances that killed the bacteria from those affecting the motility).

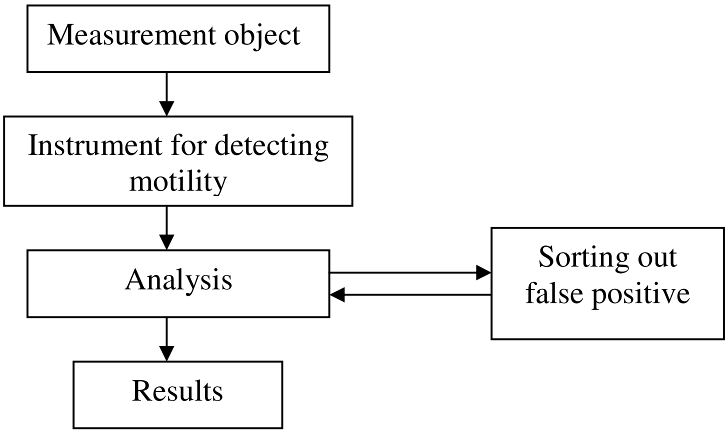

Fig. 2 Overview of the Biotech system. Items 1) and 2) could be conferred to Measurement object, 3) to Instrument for detecting motility, and 5) to Sorting out false positive.

The both biotech project groups developed (independent of each other) two methods and combined them to a system for high-throughput screening of compounds that inhibits bacterial motility. The first method, motility assay, uses a 96-well plate containing motility agar and different substances and the bacteria. The plate is incubated over night to allow growth and motility of the bacteria. The plate is then screened by an absorbance micro-plate reader (one plate takes about 8 min to analyse) The second method, growth inhibition assay, evaluates the hits that were received from the first screening and excludes substances that are false positive, i.e substances that kills the bacteria. This method uses 1.2 ml tubes with motility agar, resazurin and the hits from the first round. 1040 compounds of the substance library of Umeå University were screened against a motile strain of the gram-negative bacteria *Vibrio anguillarum*. Using these methods, nine compounds were identified that inhibits motility of *Vibrio anguillarum* and one was identified as lethal.

6. Forming the project teams

As is stated above, the crane project was run by one project team whereas the biotech project was run by two teams in parallel. From the project directives we determined those competences that were appropriate for each project. The requirement that each project team should contain students from at least two different study programs was fulfilled without any problem. The composition of the three project teams is found in Table 1, next page.

Table 1. Composition of the project teams with students from different study programs

	Project team (No. of students)		
Study Program	**Crane**	**Biotech 1**	**Biotech 2**
M. Sc. Engineering Physics	2	-	1
M. Sc. Computing Science and Engineering	3	1	1
M. Sc. Biotechnology	-	4	4
B. Sc. Mechanical Engineering	2	-	1
B. Sc. Electronic Engineering	1	2	-
Size of project teams (No. of students)	**8**	**7**	**7**

The Crane-project team consisted of students from four different study programs and it was anticipated that this mix was very well suited to solve the aims of this project. Also the Biotech-project teams consisted of students from three or four different study program. However, in these teams a majority (four students) of the group members came with the same biotech background and from the same class i.e they knew each other very well. This fact may have influenced the team-building.

We believe that the size project of teams (7 students) was large enough for the students to achieve the goals set in the learning outcomes. It has been reported that a small project group (3-4 students) tends to focus on technical problem-solving and works less on communication and project management compared to a larger group [1].

7. Team work and team dynamics

7.1 The Crane-project

During the execution of the project the organization of the crane project group was as shown in Fig.3. The work was divided into three parts and each sub team was responsible for the work in their own group, (a team leader was assigned in each group). In the first phase of the project, the project leader, together with the other project members, organized and determined the general guidelines for the forthcoming project work. The most part of the administrative tasks (documentation etc.) was done by the project leader and he was not directly involved in the technical work in any of the teams.

With this organisation (chosen by the project team), the project leader focused on the role as a team-leader (and did not participate in the sub-teams), and the sub-teams focused on their role of technical work and competence. This is a common way to organise industrial projects where an experienced professional project leader is the head of the project team and have only responsibility as project leader. However, this does not necessarily mean that such an organisation is suitable in an educational situation where there is a less clear cut line in knowledge and experience between the students, e.g. will the other students accept the authority of a class-mate that now has taken the role as the project leader without participating in the sub-teams? A project organisation with sub-teams also requires that each team takes responsibility for their own tasks and also that a clear communication between the project leader and the team is maintained throughout the project. It may turn out that the members of the sub-team only feel responsibility towards its own group and not for the entire project-team to succeed.

The sub-team 3, the Sensor and Obstacle detection team, did not fully succeed to resolve their tasks. Explanations to this could be that their tasks were not clearly defined in the activity plan in combination with insufficient communication between the project leader and the team. Another important reason could be that the group themselves did not communicate in a proper way their difficulties to the project leader.. Also, as discussed above, when this sub-team run into problems the other sub-teams did not feel any responsibility for this. As the responsibility of the other group members was restricted to their own groups, the Sensor group probably received very little feed-back from the other project members. During the course evaluation the team members was very well aware of this aspect.

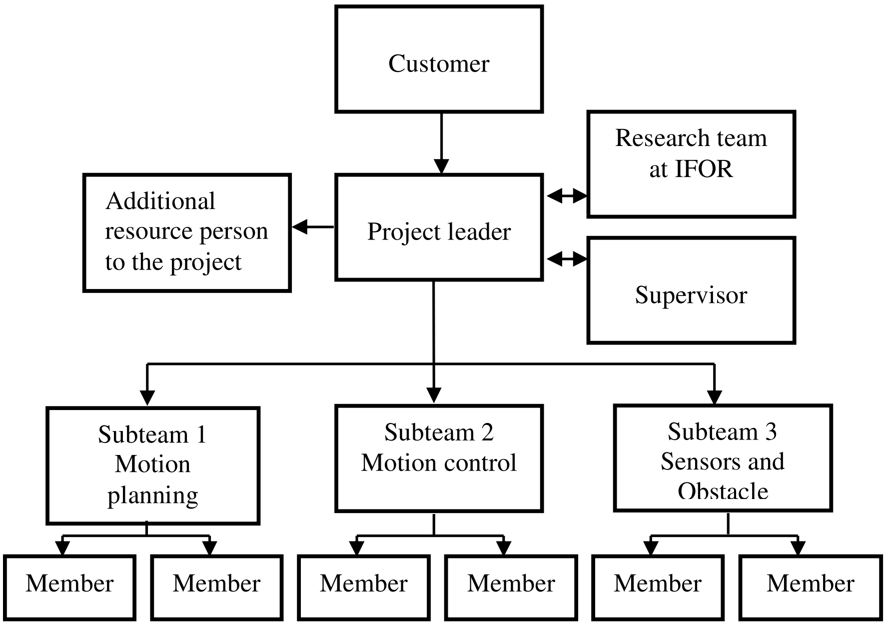

Fig. 3. Organization of the Crane project team

7.2 The Biotech-project

Both of the Biotech-project groups succeeded to develop a system where at least 100 substances could be analyzed for the effect on bacterial motility. One of the groups was successful and screened more than 1000 substances while the other group reached only 100 substances of which some of the results were not reliable.

The biotech-project directive was deliberately formulated in a rather vague and open way, meaning that there was no fixed and unique solution to the problem. The intention was to challenge the students creativity (especially those students with no bio-tech background) to bring up new non-conventional ideas. New ideas were discussed in the project-groups but were never realized, mostly due to lack of time for reflection and analyses. It soon turned out that the practical work in the lab required so much time and effort that most of the work was focused on this activity. The practical work included starting of new bacterial cultures in the morning whereafter dispensing of bacteria and substances in the motility agar was done in the evening. The readout of the results could be done the following morning. Since the specimens were biological, living material the result could only be monitored within a small time frame of 2-3 hours. This tight time schedule required the project groups to be very well organized and needed contribution from all team members.

This circumstances enforced more responsibility on the students with biotech background since they were the only ones that fully understood the procedures. In this context, the biotech students needed to educate and supervise the non-biotech members of the team. Thus, since the project mainly involved biological issues an additional burden were put on the biotech-students and only minor parts in solving the project task involved issues that required expert knowledge in the other disciplines. However, when it came to issues like dispensing the bacteria/substances in a reproducible way and the handling/administration of the result readout from the instrumentation, this required specialized knowledge that successfully was contributed by the non-biotech students.

Of the two biotech-teams, one group functioned extremely well and presented excellent results whereas the other group was able to reach the primary goal but failed to reach any further results. Both groups were organized in a similar way and had an informal project leader that wanted to have consensus decision. This worked well in one group but not in the other. A reason for this could be lack of communication and decision agony within the group.

In conclusion, both in the Crane and the Biotech groups, internal communication seemed to be important for a successful outcome of the project.

8. Evaluation of the course

The course received very good ratings from students in course evaluations and during informal discussion. Specifically, the experience to work with students with a different background was very much appreciated. Criticism was raised that it was sometimes difficult to find challenges for the students with different backgrounds. E.g. the biotech-project turned out to be mostly focused towards biology and it was sometimes difficult to engage some of the students with other background. Many of the students did not appreciate that the open formulation of project directive. Instead they preferred to have a more defined project task. However, for the students future role as engineers in industry it is important to have experience of open project tasks since real industrial projects are often not well defined.

It can also be noticed that most of the students were simultaneously with the DBT-course studying other courses resulting in a work load of 125-150% of full time. This had certainly a negative impact on the project work in the DBT-course.

9. Conclusions

This multi-disciplinary DBT-course was a challenge that provided new experience for both students and teachers. We believe that this approach with multi-disciplinary projects will promote valuable skills in the field of product and system development which is important for the students’ future role as engineers.

Acknowledgement

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