Abstract—We describe a project within the Design-Build-Test course where a student group, based on research, implemented help functions on a power wheelchair. The Design-Build-Test course at Umeå University comprises both an industrial relevant student projects 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 work together in projects, resembling the conditions for projects in the industry. We believe that this approach will promote valuable skills in the field of product and system development which are important for the students' future role as engineers.

Keywords—Design-Build-Test, multidisciplinary project course, engineering education, power wheelchair, assistive robotics

I. INTRODUCTION

In 2006, a CDIO [12] (Conceive, Design, Implement, and Operate) project course was initiated by the faculty of Technical and Natural Science at Umeå University, Sweden. Six study programs participated in this project course, of which the main goal is to implement the CDIO standards into the education. As a central part 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 in the 3rd year for the Bachelor of Science (BSc) program students, and 4th year for the Master of Science (MSc) program students.

We wanted the students to have gained a considerable technical knowledge within their own discipline, e.g., biotechnology, computer science, engineering physics, applied electronics, or mechanical engineering, to ensure that advanced projects could be offered with an industrial company as customer.

Year 2010 the course ran at 50% study pace over an entire semester, 20 hours/week (15 ECTS), from September 2010 until mid-January 2011. One project team worked on implementing help functions on a power wheelchair. We describe the process, project work, and development of this project team, and give examples of the outcome of the project. The examination was based on the following components:

- a written individual report analysing the project process in terms of self-evaluation and assessment of their own practical work,
- the project-group’s oral evaluation of the project process,
- the final presentation of the project result,
- the level of activity during realization of the project,
- the final project report, and other documentation described in the LIPS[1] model, such as the project plan, time plan, project meeting documents etc.

II. PRE-COURSE PLANNING

The students should encounter a design-build experience to learn the process to develop new products and systems in a multidisciplinary environment [2]-[4]. To achieve this goal three key elements were identified:

- involvement of interested and devoted teachers,
- relevant multidisciplinary projects,
- successful outcomes require deep knowledge of different subjects that only can be achieved by creating project groups that involves students from different study programs.

III. 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,
• present the results from a large project both in written form and orally.

IV. CONTENTS OF THE COURSE

All together 22 students from five different study program participated in the course. The course started, for all students, with introductory lectures in project management (the LIPS project model), communication, group dynamics, and team building. In addition, specific lectures for the wheelchair, the “Wheeli-group”, and the biotechnology groups, respectively, were performed to give an adequate background to the specific projects.

A. The LIPS Project Model

The projects were managed using the LIPS project model [1], which has three major phases.

1) Before Phase: During the “Before Phase”, four weeks long, 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. Here each group writes their project plan, time plan, and activity plan, which describe the execution of the project.

2) Under Phase: In this LIPS phase the project group follows the project plan, and the time plan, to meet the requirements in the requirements specifications document.

3) After Phase: Here the project is finalized. Project reports and technical reports are written. The project results, the products are handed over to the customer and the project are closed.

V. TEAM WORK AND TEAM DYNAMICS

It is very important that a group get formed and that the student feel they belong to the group and that they work on a realistic project. It is also important that the project leader takes the role as the leader seriously, and to make the roles more clear the students sign a contract.

Since the students came from different backgrounds, in this project computer science and mechanical engineering, it was important to find the strength of each individual student within the group.

After a 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 projects outcomes were demonstrated for customers and/or the industrial partners. 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.

VI. THE WHEELI PROJECT

In one of the DBT projects the students worked on a robotic power wheelchair a Permobil Corpus C350, named Wheeli, see Fig. 1. It is differential driven and has two caster wheels in the ground. It can be seen as a vehicle with a circular 2D footprint.

![Fig. 1 A Permobil Corpus C350 power wheelchair, from Permobil AB, equipped with a laser range finder (on wheelchair table), a rate gyro, and an USB interface to access the control system.](image)

The power wheelchair is equipped with a computer interface, a laser range finder, and a rate gyro. Through the computer interface it is possible to read the joystick values, set the velocity and turn rate of the wheelchair. Through the interface it is also possible to read the current and the voltage over each motor.

VII. BEFORE PHASE – WHEELI PROJECT

A. Project Description

Four students, out of 22, wanted to work in the Wheeli project. The students booked a meeting with the customer who presented the project for the group. The project description, a document that describes the expected outcomes, was handed over to the group. The project description was formulated as follows:

“The project aims to create a wheelchair that can be used by an individual who is paralyzed from the neck down, but also a control unit with multi-touch function, which can be used to steer the wheelchair at a distance such as by an assistant. The interface to the user may be directed by an air hose, tracking of head movements, eye tracking, or a computer mouse.”
It must be possible to mount the hardware on the wheelchair, for instance on the backrest or the wheelchair table.”

The task given to the project group was to implement assistive functions, and make a simple Graphic User Interface (GUI), where the user could select different supportive navigation functions on the Wheeli.

B. Scenarios

The customer also described scenarios to make the implementation of the help functions easier.

1) Scenario 1: A wheelchair user must be able to drive between two buildings at Umeå University, from “Teknikhuset” through a skywalk to the “MIT” building and back within 20 minutes based on GUI control and the implemented help functions. Some difficult areas involve walls of glass and iron fences. A staircase, leading down, can also be seen as a severe obstacle since it can not be detected when the sensor is mounted in horizontal position.

2) Scenario 2: A wheelchair user must, based on the GUI be able to drive the along the pedestrian walk. The pedestrian walk is around 300 meters in distance. The wheelchair must be able to follow a pedestrian walk outside semi-autonomously.

C. Project Perspective

Possible perspectives to the described project were also presented to the group:

1) User Perspective: A user who can use his wheelchair as support so that the risk of collision with objects in environment decreases. It gives a kind of freedom.

2) Manufacturer's Perspective: One can imagine that wheelchair manufacturers are happy to provide a wheelchair with help functions.

3) Assistants Perspective: Severely disabled patients often have one or two assistants. Some auxiliary functions can be of interest to them, such as the "Follow me" function.

4) Economic Perspective: A wheelchair with help functions can reduce the need for assistants.

5) Relatives Perspective: It may be so that relatives of a severe disabled wheelchair user will be pleased if a user can drive the wheelchair by self.

D. Assigned Roles in the Project

After the project description was handed over to the students, the process of forming the group started and they were assigned to set the following roles within the group:

• a project leader,
• a project member responsible for the economy,
• a project member responsible for the handling of documents within the project,
• a project member responsible for the implementation,
• a project member responsible for the hardware,
• a project member with responsibility for tests.

The project specification also stated that no group member was allowed to work more than 300 hours on the project. So it was very important that the time planning works, and continuously updated during the project.

VIII. ANALYSIS OF THE REQUIREMENTS SPECIFICATIONS

In a meeting together with the customer and the project group the wheelchair help functions were given different priority levels; high, normal, low, and removed priorities.

A contract was signed, between the group and the customer, which stated that the group must focus on deliver functions in high and normal priorities. If the group has additional time they also work on the delivery of functions with low priorities.

A. Functions with High Priority

1) Collision Avoidance: Based on streamed data from a laser range finder, SICK S300, and algorithms the wheelchair must avoid detected obstacles in the environment [5]. It must also prevent a user from hitting objects.

2) Emergency Stop Functionality: It must be possible to emergency stop the wheelchair through a button that is easy to reach for the wheelchair user. An activated emergency button must directly stop the vehicle. There must also be a way to emergency stop the wheelchair on distance through a radio link, for example WLAN.

3) Design of an User Interface: It must be possible to execute driving commands through a GUI, Graphic User Interface.

4) Graceful Motion: The wheelchair must move gracefully [6].

5) Shared Control: The power wheelchair and the user must be able to control the wheelchair [7], where the user always can override the system.

B. Help Functions with Normal Priority

1) Map Building: Pose the wheelchair on a representative map that represents of the users’ environment.

2) Follow Path: Here the wheelchair follows a known path outdoors. A scenario was created for this.

C. Help Functions with Low Priority

1) Detection of Known Objects: Through a web camera the wheelchair system should recognise known objects in its environment. This to feed the navigation software with reference points, to localise the vehicle. This would require a database of objects.

D. Functions Removed from the Priority List
1) **Follow Me**: The power wheelchair follows a person, also in a dynamic environment where for instance many people are present,

2) **Innovative Design**: New ideas regarding control and use of the wheelchair,

3) **Tactile Display**: Information shared to the user by vibrations through small electrical motors placed on the backrest and on the seat.

### E. Project Priorities

The project description also informed the students about how they should prioritise delivery time, project budget, and project result.

1) **Delivery Time**: it is important that the project reach the high priority help functions at the project end.

2) **Project Budget**: the group may be allowed to exceed the budget, if that is needed.

3) **Result**: the group does not need to deliver all functions for the power wheelchair.

The hardware/software handed over to the student group were the following:

- Permobil Corpus C350 power wheelchair with USB computer interface,
- a laser range finder, SICK S300 with USB interface,
- a Dell Latitude 2100 netbook computer with Windows XP and MATLAB,
- Tobii C12 Eye tablet computer,
- a rate gyro with USB interface,
- USB Interface to power wheelchair,
- a digital camera for documentation,
- a 20 channel USB GPS receiver,
- a Logitech 9000 Pro USB web camera,
- software to interface the wheelchair and Java for accessing the wheelchair, and a skeleton to the GUI[11].

### E. Project Milestones

1) **Milestone 0**: Sept.6 2011 – The customer presents the background of the project and hands over the project charter to the students.

2) **Milestone 1**: October 1 2010 – Project plan and system sketch is ready.

3) **Milestone 2**: November 2 2010 – Project status presentation.

4) **Milestone 3**: January 11 2010 – Delivery of product and official project presentation with live demonstration.

### IX. DURING PHASE – WHEELI PROJECT

The customer provided some code as a starting point, MATLAB interface to the sensors, and the wheelchair control system. The student also got a simple GUI that had some of the basic functions implemented.

#### A. Project Budget

The students were given a budget of 12,000 SEK, approximately 1200 Euro, for the project. The money they could use to buy material to the project, and the group. They could also consult an expert for 15 hours.

#### B. Scheduled Meetings

1) **Group Meetings**: The group had weekly meetings where they discussed what needed to be done, and distributed work between the team members.

2) **Meetings with the Supervisor**: The meetings were scheduled on Monday afternoons, at 15:00, and approximately one hour long meetings. The project leader made an agenda for the meeting. The meetings were documented and uploaded to the Moodle platform where the group kept all their documents.

#### C. Halfway Presentation for the Customer

At the presentation, the supervisor acted as a customer and invited the group for an oral presentation about their advancements in the project. The presented information is about what the customer can expect and what to be delivered as well as some preliminary results. The group demonstrated some preliminary results on the wheelchair, see Fig. 3. They also stated what they will be able to deliver, and made a warning about a high priority function that they would not implement; the possibility to emergency break the vehicle remotely over a wireless link.

The group had mounted a safety switch on the right side of the power wheelchair that cut off the power to the wheelchair when it is activated.

![A laser range finder](image)
D. Test Protocols

The student made a test protocol to evaluate the implemented functions. The students identified things in their testing document. Some of them are listed below, and also referred to the requirement in the requirements specifications:

- The user should feel that he has control of the wheelchair (Requirement 1).
- The user should not be able to drive forward into a wall (Requirement 2).
- The wheelchair must be able to drive autonomously around a stationary object in the middle of a room (Requirement 8).
- The wheelchair should be able to pass an obstacle without collision. The wheelchair will not run into the moving objects in front of it (Requirement 9).
- People should be able to pass the wheelchair in motion at a reasonable distance without risking that the wheelchair runs into them.
- The user can choose a driving direction that the wheelchair will try to keep (Requirements 4).
- The user can control the wheelchair using the existing joystick (Requirement 15). Several test drivers will drive the wheelchair and feel they have are in control.
- The user should be able to tell the wheelchair to keep to the right or left in a corridor (Requirement 6).
- The user can drive the wheelchair via a user interface on the computer (Requirement 17). The wheelchair must be able to follow a wall to the right or left side of a corridor.
- The user should be able to turn 90 or 180 degrees to the right / left (Requirement 7).
- The user can control the wheelchair via an user interface on the computer (Requirement 17). The wheelchair must be turned 90 degrees to the specified direction.
- The wheelchair should be able to detect obstacles from floor level up to the sensor height (Requirement 10). The wheelchair must detect obstacles at a reasonable distance.
- Acceleration of the wheelchair must be graceful, without jerks (Requirement 11).
- The user should be able to steer the wheelchair with the eyes using Tobii's products CEye (Requirement 18). The user can use the graphical user interface with the eyes.
- It must always be possible to manually override the help functions (Requirement 19). The wheelchair will stop and turn off when the user presses the emergency stop button.

X. AFTER PHASE – WHEELI PROJECT

In the after phase the students have to deliver the following items:

- final project report.
- a reflection document in which each project member describes his/her role in the project,
- an oral presentation about the outcome,
- return the borrowed and bought equipment.

A. Updated Budget

Updated budget – The student group used 6600 SEK of 12000 SEK for their project. The biggest cost was the purchase of a Acer Aspire 5471G laptop computer with a quad-core processor. The student did not have their own laptop computer, and the netbook and Tobii tablet computer provided to the group was not good for software development. The student’s had access to one stationary computer in their project room, and more stationary computers in nearby computer labs.

B. The Final Project Report

The report covered the implemented functions on the vehicle.

C. The Individual Reflection Document

Each student wrote a personal document in which he/she reflected over their own role and work in the project group. It also covers the dynamics in the group and their own place in the group. In the reflection document sometimes the students describe things that are hidden from the other group members, such as workload, skills, and conflicts.

D. Final Presentation and Demonstration of Project Result

All the four members in the project group participated in the presentation.

After the oral presentation the student group demonstrated their final product.

E. Returning Borrowed Equipment

Before the student returned the equipment they checked their inventory and made an inventory list where all items
XI. PROJECT RESULT

One of the employees at the university took the chance to test the Wheeli power wheelchair when the project group demonstrated the system, see Fig. 4.

Fig. 4 An employee at Umeå University tests some of the implemented help functions when the students demonstrates the the project result, directly after the final presentation

A. The Graphical User Interface

The graphical user interface was designed with big buttons and also shows sensor data in real time, see Fig. 5. The current sensor data and processed sensor data, from the laser range finder, are visible in the middle of the GUI.

Fig. 5. The GUI with buttons for assistive wheelchair functions. Sensor data are and processed data are visible in the centre.

The GUI buttons, visible in Fig. 5, are:

- **turn left / right 90 degrees** – changes the wheelchair heading 90 degrees left / right,
- **go forward** – drive forward with automatic control and the systems makes sure the wheelchair drives where there is free space,
- **shared control** – the user place a destination with the wheelchair joystick and the wheelchair system makes sure the there is no collisions,
- **manual control/stop** – take manual control of the wheelchair.

XII. RESULTS AND EVALUATION

The course was evaluated in several ways:

- analysed feedbacks from project students (individual reports),
- analysed feedbacks from students through the Moodle platform,
- comments from teachers and project supervisors,
- on project results.

A. Comments and feedback from the students

Some comments from the students:

- it was too much documents to write in the before phase,
- it worked well to work in pairs (within the group),
- Moodle[13] was used as a communication platform,
- the project meetings on Mondays were good,
- the project room was good,
- it was a special situation when the supervisor was the specialist and at the same time acted as customer,
- the LIPS project model is not suitable for programming project, and they argued that an Agile project model had better since it was a programming projects, and widely used by software companies.

B. Comments from the Teacher

The Wheeli group was not that satisfied as new hardware was introduced some weeks after the project started the Tobii Ceye tracker. As a teacher we could have argued that the students should call for a meeting with the customer and discuss things written in the requirements specifications document.

What could be observed by the teacher is that the student study other courses at the same time, and that therefore the time plan needs to be written seriously from the beginning. Often labs and exams in other courses collide with planned time in the project.

C. Other Comments

The customer also wanted the group to test out a new 3D time-of-flight camera [14], the Fotonic B70, but the group said that they had enough workload as is.

Based on the results both the customer and the group came to the conclusion that the current sensor cannot be used in a real life setting since it measures ranges in 2D. It is important that a sensor can sense obstacles on the floor and up to around 1.7 meters above the ground in front of the vehicle. In this
setting, as shown in Fig. 4, it was a problem to see obstacles on floor level.

D. Course feedback from students in Moodle

At the end of the course, the students were asked to fill out a course evaluation with about 20 questions on the learning platform Moodle. The course received in general good ratings in the evaluation. One of the main questions was: “How would you assess the overall quality of this course?” The response to this question was an average rating of 4 (on a scale where 5 means very good and 1 very bad). Along with each question, the students could give comments. We noticed that the Wheeli group was not that satisfied as new hardware was introduced.

E. Evaluation of the Evaluations

The course evaluation is a very important tool for the teachers and supervisors to improve the course. Our web-based evaluations are optional, which is a problem. Although the students handed in the questionnaires anonymously, not all of them completed the evaluation. Only about 2/3 of the students made it. The results from such an evaluation may be of lower relevance than if all the students taking the course participate in the evaluation.

XIII. CONCLUSIONS

It is important that the project group get formed immediately in the beginning of the course, and that the goal is clear. The goal must not look too easy so that the student get motivated to solve the problem. It may be so that the students get more devoted if the customer pays some sort of grant on a successful delivery. Sometimes it seems like the students focus on other courses and do not work more than necessary to pass the course.

It is important that the project leader is motivated, since he is maybe the most important person in the project.

The red line was the project plan that was written at the start of the course. It needs to be stated that it a living document that sometimes needs to be updated during the project.

We also believe it is important that the students must be taught to follow the project plan and not work on things that are not stated in the contract with the customer, the requirements specifications, since the final delivered product is scored against the requirements specifications.

XIV. DISCUSSIONS

Our CDIO course, Design-Build-Test (DBT), is an interesting course where students, researcher, and industry can work together on prototypes development as well as research problems.

Regarding the technical content, a comment is that the students were not that satisfied with the SICK S300 sensor since it had limited view in 3D. Of course the Kinect sensor by Microsoft is promising in this aspect; it is cheap, has fairly good range and good view angle, and has a rather high frame rate.

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