MULTIDISCIPLINARY PROJECT-BASED PRODUCT DEVELOPMENT LEARNING IN COLLABORATION WITH INDUSTRY

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Abstract

Developing products is a multi-disciplinary process of identifying and envisaging user needs and realizing a product offer that meets these needs. This has to be done in a cost-efficient manner, while ensuring that the developed products exceed customer expectations concerning functionality and quality, and that they stand out from competition. Running project-based education in collaboration with industry allows students to gain experiences in addressing "real" problems and skills in applying industrial working practices in an industrial context. Consequently, product development organizations deliver not just the technical design of the product but a complete product offer. This involves activities such as market analysis, product planning, industrial design and development of after-market services.

Some ten years ago, Chalmers University of Technology changed its Product Development project course, which addresses these needs, in order to increase the industrial collaboration and to facilitate a more multidisciplinary project composition. The course is now open for 4th year students from many disciplines including Mechanical Engineering, Automation Engineering, Industrial Management and Industrial Design. Thus, the student teams are multidisciplinary, which enables them to take on a multi-faceted, industry-sponsored product development task. The task requires that all the phases in a product development process are carried out. The students get the opportunity to appreciate that skills possessed by other disciplines are necessary to solve a complex problem, as well as the challenges involved including differences with respect to goals, culture, and disciplinary terminology.

Keywords: Project-based learning (PBL), Multidisciplinary teams, Industrial Collaboration

Introduction

Project-based learning is a popular element in product development programs because of the educational benefits they deliver [1]. PBL does address a key issue in engineering competency, namely transfer, which may be defined as the ability to extend what has been learned in one context to other, new contexts [2]. In addition, PBL changes the role of the teacher to a cognitive coach who models, coaches, guides and encourages independence in goal setting and decision making and promotes reflection [3]. In 1997, work began to update the existing project course in Product Development for 4th year students in the Mechanical Engineering programme at Chalmers University of Technology. This project course requires approximately 8 weeks of

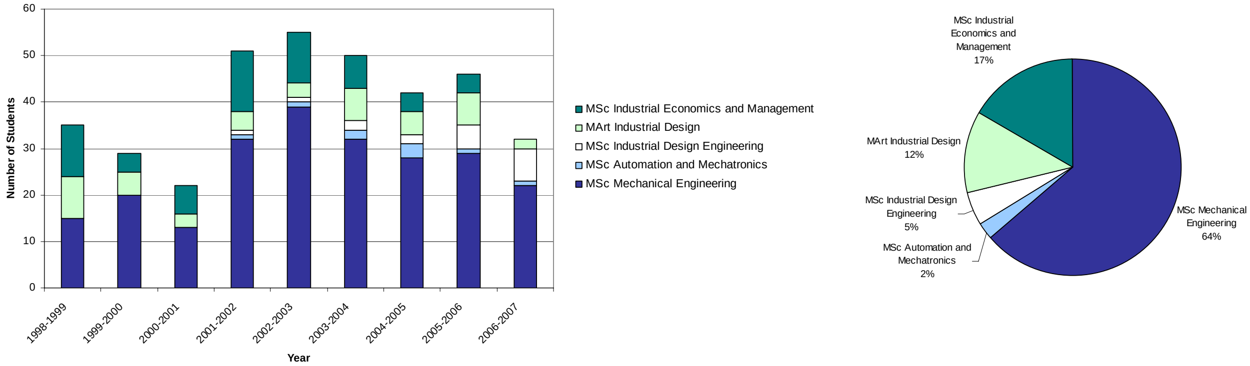

Figure 1. Statistics of student participation in the Product Development project course from 1998 to 2007

full time work from each student and runs from October to late May. Since the start of the course in 1998 we have overseen 54 projects with 362 students, see Figure 1.

There were mainly three important driving factors for updating the project course. First to increase the industrial cooperation by having product development projects with direct benefit to the industrial sponsor, in order to expose students to the industrial environment in which products are developed. Second, to let student manage their own budget in order to increase the student groups possibility to carry out their task (e.g. fabricate highly developed prototypes) and increase their overall responsibilities. The third and final rationale for a change was to increase the co-operative aspects and involve not only Mechanical Engineering students but also students from Industrial Economics and Management, Automation and Mechatronics Engineering, and Industrial Design. This made it possible for students to appreciate the skills and attitudes adopted by other disciplines and learn from each other. This paper will address our experiences of providing this cross-functional product development project course.

Course Description

The base for the course is the “real” product development project assigned to the student team of an industrial company. This sets the scene for the course and how it is planned, organized and carried out. Each team is assigned its own project of its own company with which the team is interacting throughout the whole course. Nature and scope of assignment, identified deliverables and company engagement thus differ between projects, and that must be handled to meet the necessary conformity requirements that the course needs in order to make fair judgments of the different teams achievements.

Course Administration

The course examiner, which is a senior faculty member, has the overall responsibility for the course. For planning and administration of the projects the examiner is supported by a course assistant, who is a PhD student. The examiner does the overall planning (including resource planning and budget), gives an introductory lecture, monitors the progress in the projects, leads the final examination work and takes the final grading decisions. The course assistant does the detailed planning (time schedule, forms project teems together with the examiner), organizes the compulsory events connected to the project (project introduction, team-building activities, stage gate presentations, project exhibition and final project presentations) and participates in the final examination work.

A very important part of the examiners work with the planning is to establish and maintain good contacts with companies that can provide project assignments. This is crucial as the success of the course totally depends on good projects. The final selection of projects is done in cooperation between the examiner, the course assistant and academic project supervisors.

Administration connected to individual projects is handled by the project supervisors. In each project, there is an academic supervisor as well as an industrial supervisor from the project assigning company. The industrial supervisor helps the student with administrative matters connected to the company as part of the industrial supervision task. The academic supervisor, who can be a faculty member or a PhD student, takes care of the administrative issues concerning the project and the university (coordinates resources, signs for expenses, etc.) as part of the academic supervision task. Both the examiner and the course assistant can also be academic project supervisors. All academic supervisors take part in the final examination work.

Acquiring and selecting Projects

In mid August each year the examiner initiates the project acquisition process. Through the years different combined approaches to acquire project proposals have been tried. Examples of such approaches are:

- broad proposal invitations in letters and/or emails to some hundred companies
- directed proposal invitations in letters and/or emails to a selected limited number of companies
- use of examiners and supervisors personal company contacts
- ask for proposals from an established and gradually extended network of companies that are familiar with and interested in the course

Of these four approaches the two first have given poor results whereas the two last have shown to be the only ones working. They require a lot of work, however, in particular from the examiner, in terms of calling, emailing, reminding and re-reminding and so on. In the beginning of this process the contacted companies are informed of the following requirements that we have on the projects. Projects should:

- be of direct benefit to the industrial sponsor
- be suitable for 5-7 students and equivalent to 8 weeks of work per each from the end of October to the end of May
- contain marketing, engineering, and industrial design elements
- be industrially sponsored with an appointed professional engineer as supervisor and a project budget

In return for the engagement the company will get a project result based on some 2000 man-hours of engineering work at a total cost in cash of 30 kSEK (≈ 3000 €).

When the proposals have been submitted, the 5-7 (depending of the number of course participants) that best fulfill the stated project requirements, and best fit the background of the participating students, are selected after evaluation by the examiner, the course assistant and the academic project supervisors.

Establishing Project Teams

Two to three weeks before the start of the course the descriptions of the selected projects are presented on the course home page, and all students who have signed up for the course get a personal email to make them aware of this. In the email they are also invited to a presentation where the academic and/or industrial supervisors will present the selected projects. After this presentation the students are instructed to pick three projects and rank them as 1st, 2nd and 3rd choice. The result must be mailed to the course assistant within a week.

Considering the students choice, each students´ disciplinary background and the contents of the different projects, the examiner and the course assistant compose the project teams. The aim is to have the best possible disciplinary team composition for each project while considering each students´ choice. Most students normally get their first or second choice. Sometimes a third choice must be accepted, but it is very unusual that a student is placed in a non-prioritized project.

The course starts with an introductory lecture given by the examiner, and in connection with that the proposed project teams are presented. The proposal is discussed and may sometimes be subject to minor changes before the composition of the teams is finally decided. Each team then has a first meeting with the academic supervisor when they discuss the project and plan for a first meeting with their company and their industrial supervisor. To initiate a team-building process each team has a two hour meeting with a psychologist connected to the course. This takes place within a week after the start of the course. Together with the psychologist the teams discuss psychological profiles, roles in groups and group dynamics in order to make them aware of and better understand potential future collaboration problems and how to deal with them. At this occasion they are also invited to contact the psychologist if future collaboration problems, that the team members can not solve themselves, occur.

The formation of the project teams is finalized by the teams themselves. Each team must appoint one student to be responsible for the teams´ budget and for handling all economic transactions that the project will have with the university and others. Apart from that the teams are free to organize themselves the way they like. Normally different team members take responsibility for project issues related to their disciplinary background. The question of leadership has been handled differently by different teams through the years. Some examples are: one project leader for the whole project period, different project leaders for different phases of the project, rotating project leadership with change after a certain time and collective leadership without an appointed project leader.

Project Assessment

After the project teams have been established and the initial discussions with the company and the industrial supervisor have started the project is assessed and the detailed planning of the project begins. All projects must apply the prescribed state-gage process model shown in Figure

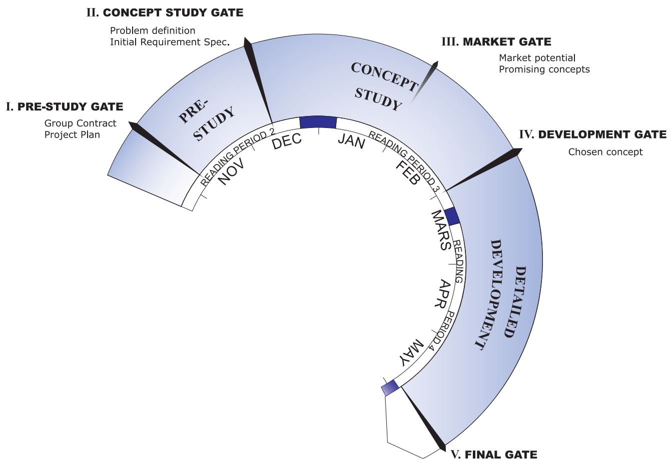

Figure 2. Stage-gate process for the product development project

2. The process is divided into three main stages, each one ending with a gate with prescribed deliverables.

At each gate there is a design review where the status of the project and the deliverables are presented to all participants in the course, all supervisors, the course assistant and the examiner. Deviations from the plan are discussed as well as measures to be taken to handle such problems. What has to be done in order to proceed into the next stage is also identified. A status report containing the results of the review is written and the project plan is updated. At the last gate the design review is replaced by the final project presentation which consists of a project seminar and a project exhibition. A printed version of a written project report must be made available one week after the final presentation.

The project course is supported by two product development methodology courses running in parallel with the project course during the first two thirds of the project. The aim of the supporting courses is to provide the project teams with suitable and efficient development methods and tools that can be used in the project work. The teams´ ability to adopt and make use of these methods and tools is an important aspect when judging the performed work and the achieved results.

An important part of the final project result is the models and prototypes developed and manufactured in the projects. The major part of the project budgets is normally allocated to cover the costs for these models and prototypes, if they are not too complex and can be manufactured by the project team members using available university facilities. The total budget for each project is 60 kSEK (€ 6000) where half is paid by the company and half is provided by the university. If the company requires models and prototypes that cannot be handled within this budget they must provide the extra resources needed.

The examination of the students is based on:

- the teams´ and the individual team members´ performances during the project

- the results of the design reviews
- the final report
- the final project seminar
- the exhibition

The examiner, the course assistant and all academic supervisors are engaged in the examination work. This means that everybody takes part in all design reviews, final seminars and the exhibition, and they all read all project reports. The achievements of the teams and the individual students are compared and discussed considering the goals of the course. The process leads to a consensus proposal of the grading of each project and team member. The examiner takes the formal grading decision.

Project Execution and Result

The execution of these projects has to be done in a cost-efficient manner, while ensuring products that exceed expectations on quality standards in form, fit, and function – and stand out from competition. Our primary goal is to achieve customer value and satisfaction and consequently we put a lot of resources into understanding customers' latent and explicit needs. All projects follow the same stage-gate process (see Figure 2) with three main phases: pre-study, concept study, and detailed development. However, considering the various projects and their different focus deviations naturally occurs.

Pre-Study Phase

During the pre-study phase students form their groups and establish a group contract. At the first pre-study gate the group should present themselves, their view on the project together with an initial project plan (with activities, dead-lines, and responsible) and budget. The major work during this phase is to scrutinize the given problem definition from all stakeholders' perspectives. This often includes discussions with representatives from the company and sub-suppliers, interviews with lead-users, questionnaires, observations and use of the considered product. At the concept-study gate the group is expected to present a detailed in-depth analysis of the given problem. This gate should answer for instance which stakeholders that must be considered and their expectations, which customer segments that are in focus and existing competition (price, functionality, performance, and advantages/disadvantages). This should be documented in a problem definition, including customer requirements transformed into technical requirements.

Concept Study Phase

During the concept study phase students should continue analyzing the problem with a focus on market prerequisites (market channels and -instruments, supplier networks, trade barriers, politics, regulations and laws, and immaterial rights) while starting to form conceptual solutions. At the intermediate market gate all groups should present this so that the faculty and all involved students in the course could give suggestions for the forthcoming conceptual work.
All groups are encouraged to develop a large number of conceptual solutions to various degrees of abstraction and detail. This exploration is done both internally (structured group methods for concept formation) and externally (searching for ideas and solutions in literature, suppliers and internet, visiting fairs etc.) and documented in a structured fashion (see Figure 3) – something

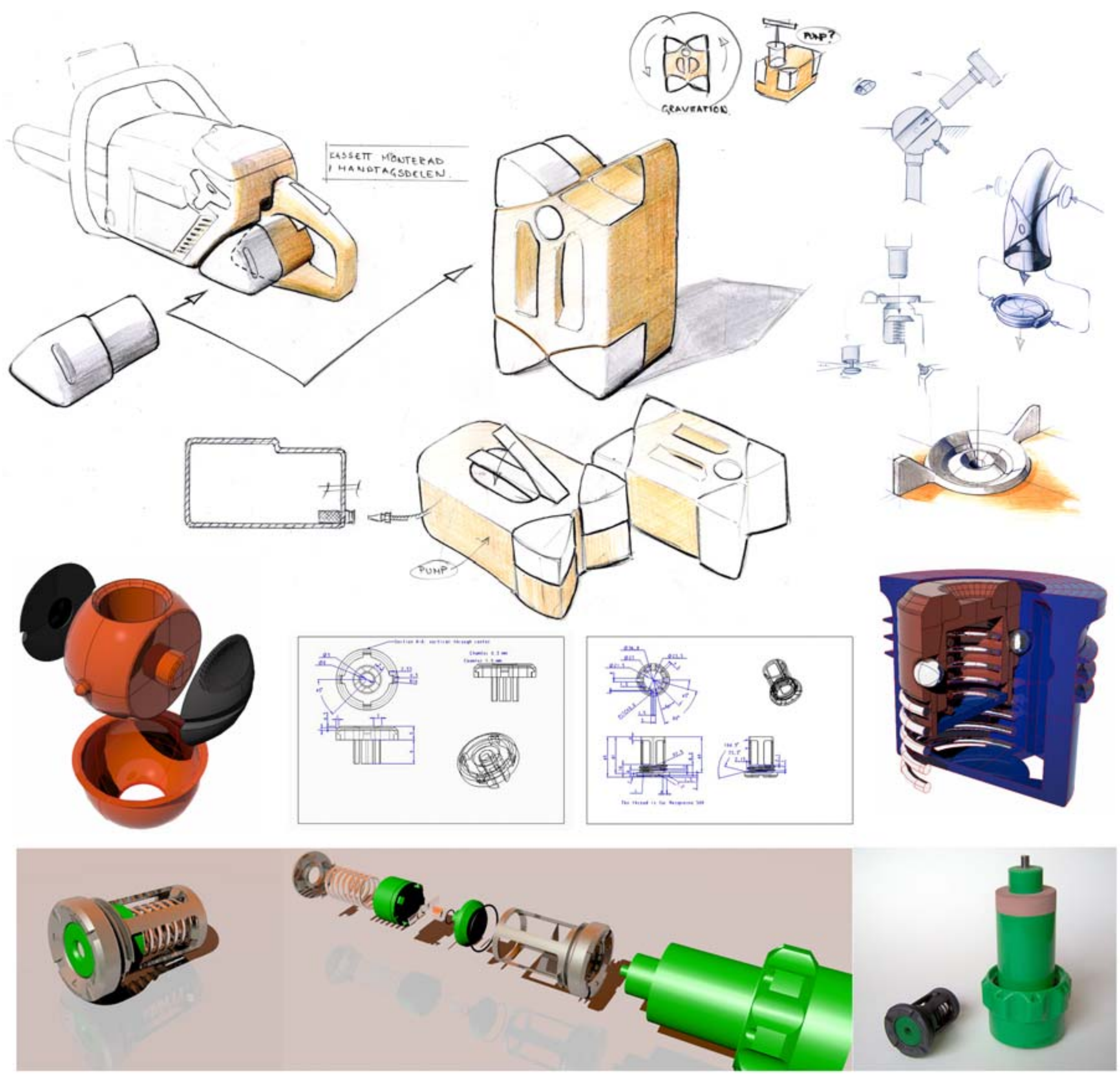

Figure 3. Development of an easy and environmental-friendly refueling system for chainsaws, performed by four Mechanical Engineering students and one student from Industrial Economics and Management from Chalmers and one student from the Industrial Design programme at the School of Design and Crafts, Göteborg University in 2005.

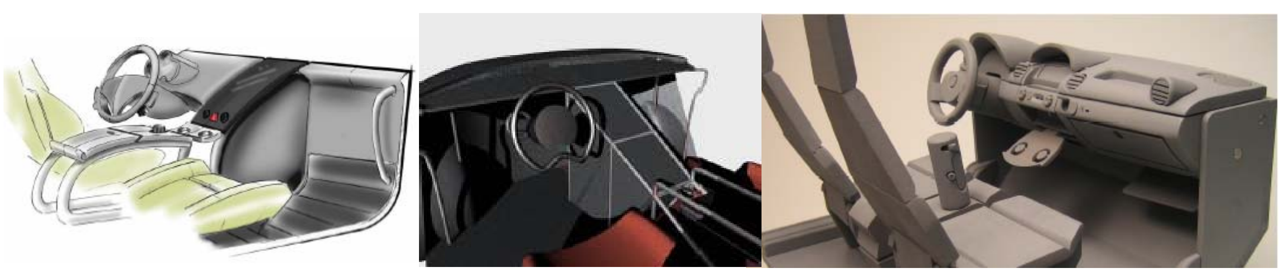

Figure 4. Development of a modular instrument panel, performed by five Mechanical Engineering students one student from Industrial Economics and Management from Chalmers and two students from the Industrial Design programme at the School of Design and Crafts, Göteborg University in 2006.

that is very appreciated by all companies. Using structured methods for concept selection and discussion with the company the material is step-wise condensed so that a concept solution can be selected for detailed development. Sometimes the company wants to test several interesting ideas, often a more traditional solution for an early implementation and one more futuristic solution. This decision is made with all involved actors (students, company, and supervisor) to secure all interests and learning outcomes.

Detailed Development Phase

The aim of the detailed development phase is to develop basic data for the manufacture of a prototype. The prototypes are most often produced at Chalmers prototype laboratory or at the specific company. Many prototypes are also manufactured using rapid prototyping (see Figures 3 and 4). Irrespective of the choice of equipment this process is led by the student group and they are encouraged to take an active part in the manufacturing since it creates such a good feedback to the design of the finished product. In parallel, work is carried out to assess the commercial potential for the chosen design, including market potentials, customer acceptance, manufacturing cost, and price strategies. The purpose with the analysis is to make a total assessment of the economical potential in the project from gathered material. This work is a synthesis of economical, technical and market factors. During the final gate in late May, the project is presented orally and all material is exhibited on show for all interested parties.

Discussion

Product Development must be viewed as an explorative process, where the possible designs to be searched for are not necessarily available and where we are not necessarily able to address the needs at the project start. From an academic pedagogical perspective it is apparent that we are promoting students development of the ability to understand the situation at hand, to act upon uncertain information and reflect upon the actions taken. We believe that project-based learning with industrially initiated projects is essential in order to achieve this learning outcome, especially when you encourage students to scrutinize the initial problem definition.

Student Benefits

Our experiences are that the multi-disciplinary projects give students extensive understanding of:

- product development much like how it is done in the industry.
- project work, including the planning and management needed to be successful.
- Activities necessary in order to develop a successful product and the methods and tools available to reach this goal.
- the skills and attitudes adopted by other disciplines and what they can benefit with in a development organization.

Although students will be more responsible for their own learning process students get much better qualifications in cooperation and project work.

Industrial Benefits

The benefits for the company can be categorized in primary and secondary effects. The primary effects include the project performed and its results. Although the result is not put into production and offered to customers there are elements in the project that will certainly affect the direction of future projects within the company. Consequently, the companies that we have worked with find a market study, well-documented requirement specification or prototype of equally great value. The secondary benefits include the chance to get in contact with students and get exposed to many new methods and tools for product development. But most of all the companies value a completely new perspective on their products and the problems they perceive.

Academic Benefits

Although it probably puts more work on senior staff in supervising these projects it is certainly worth the effort, because in addition to the learning outcome for students it also gives a rich empirical material that can be used in education and research.

Since we want students to work with real design problems as they present themselves in industry, we do not "polish" the projects in advance. And since we want to emphasize the ability to define the scope and problems and not only to find the solutions and answers, we leave it to the students themselves to find out what to do and how to organize the work. This makes it somewhat hard to prescribe a set of procedures, methods and tools that should be used in order to speed up the process. Rather, this is a task for the academic supervisor who guides and encourages students in their planning process.

Areas for concerns

Using PBL in an industrial setting with multi-disciplinary groups stress some areas for concern:

1. *Project Scope Creep.* When companies are asked to propose projects, their level of readiness to do so differ from picking proposals from a list of already identified, prioritized, analyzed and formulated problems to just propose something in a haste that might be of interest but is poorly understood and vaguely formulated. Most project proposals are of course somewhere between these two extremes. In the first extreme category there are usually problem owners within the companies that are interested, motivated and potentially good industrial supervisors. In the second extreme category there are seldom such problem owners. The proposals here, as well as more ore less similar ones, cause problems. As they are poorly understood and described they are hard to evaluate. They might be too difficult or too large, or external problems and not foreseen complications can make them impossible to carry out according to the original scope and plan.
2. *Visible cooperation problems in groups.* We have had a few groups which have run into cooperation problems. The causes might have been differing opinions concerning project actions, mismatching personal styles ('personal chemistry') in the teams, disagreements on distribution of work load between team members and undertaking of responsibilities or other things. Our interpretation so far is that problems have most often been based on disagreements on the direction that the project is taking, rather than personal aspects. These different issues could however be coupled which is a circumstance that we so far have paid little attention. When visible problems have arisen they have been dealt with. In these cases

we always take the group to a neutral place and sit down with the appointed social psychologist and discuss the matter to form an action plan.

3. *Non-visible cooperation problems.* This might happen when the group accepts that members don't do their job and cover up for them. Probably, this is natural since the project runs for a long period and students' engagement in other courses varies over time. However, when there are requirements on individual assessment and grading of students it is vital to introduce new elements to lure out indications on this phenomena. Another (when it occurred) non-visible cooperation problem that we have discovered is that project teams occasionally have been split in informal sub-teams taking on different tasks without close collaboration between the sub-teams and thus jeopardizing the over-all project outcome.
4. *Supervisory cooperation problems.* Since each project relies on an appointed industrial supervisor it is crucial that the external industry partner allocates resources to discuss and explain the task with its involved problems, follows up the students, answers questions and gives feedback on work done or delivered subsystems. This is also relevant when it comes to the academic supervisor.
5. *Teacher-centered (Proactive) vs. Student-centered (reactive) supervision.* As a supervisor in project courses such as this, one has to balance between being proactive (suggest procedures or solutions and take decisions) and being reactive (wait for students to act and comment) in order to give students both general guidance and encouragement as well as specific support. It is of the outmost importance for supervisors to find a balanced way to support and supervise the teams without becoming extra team members doing the real team members work.
6. *Students stick to what they have in common.* Members of heterogeneous groups have a tendency to stick to what they have in common (as in focus groups [4]) and that could sometimes be the case in earlier phases of these kinds of projects. It takes a while before students start to criticize each others work and propose things that they know are controversial for other disciplines. Over the years, we have also seen a tendency that teams, in which the members know each other and have found their "common denominators", are reluctant to leave this common domain when looking for problem solutions and ways of working. The safe route to follow is to do what all team members can relate to even though better solutions are to be found outside this domain.
7. *Project Workspace.* These projects gather and generate a large amount of information and material necessary for the successful execution of the project. Therefore, it is vital to provide a stimulating accessible work space for these groups.
8. *Student Assessment.* Considering that this course runs for over three semesters (November-May) there is a risk that students don't get proper feedback on their achievements, since they find it difficult to document their work in full extent since so many things may happen during the progress of the project. Up to date we have solved this with more formal gates in the project and project related activities in parallel courses (e.g. having students submit a tolerance analysis of their design in a parallel course and thus be formally assessed and graded there). In addition, we are faced with the challenge to have to grade students in project groups individually, which requires more delicate ways to assess individual achievements in the teams.

Measures of improvement

1. *Project Scope Creep.* Precautions have to be taken in the project acquisition process so that problem projects of the first category and similar can be avoided. The means to do that are twofold. First, the total number of proposals must be big enough to allow rejection of potentially problematic proposals leaving a required number of unproblematic or good project proposals. Second, means to identify the problem proposals must be developed. Both issues require handling of industry involvement, and our approach is to widen and strengthen our network of companies participating in the course. Our goal is that this network shall contain committed companies of the first category that themselves gain experience from participating with projects and thereby get an understanding of required project contents and how proposals need to be described.
2. *Visible cooperation problems in groups.* We need to work more proactively in order to avoid cooperation problems, and we must also improve our ability to understand the problems that arise and how to deal with them. Potential measures to be taken are to consider personal styles and psychological profiles when composing the project teams, to give the academic supervisors basic training in group psychology and to further develop the involvement of the psychologists now participating in the course.
3. *Non-visible cooperation problems.* The supervisors´ involvement is essential in order to early identify and handle these kinds of problems. Besides being trained in group psychology in order to understand the student team and its members a team supervisor must also be able to build deep and enough trustworthy relations so that non-visible cooperation problems can be identified. This kind of skill can probably only be gained from experience. Once identified the non-visible cooperation problems have become visible and should be dealt with accordingly.
4. *Supervisory cooperation problems.* The main part of this problem is related to the commitment and engagement of the project proposing company. By acquiring good projects from committed companies (see 1) that understand and agree on the project requirements and the prerequisites for their participation these problems should be possible to solve.
5. *Teacher-centered (proactive) vs. Student-centered (reactive) supervision.* The means to come to grips with this problem is to include supervisor training in PBL project supervision. It is also important for project supervisors to share experiences related to this problem with each other. It might therefore be a good idea to arrange supervisor seminars on this theme for the supervisors involved in the course.
6. *Students stick to what they have in common.* Measures should be taken to make team members bold and more open to ideas and impressions from areas outside their own domain of knowledge, especially in the initial phases of the projects. We therefore now plan to introduce enhanced team-building activities in the beginning of the coming project courses. In order to broaden the team members´ domain of knowledge we are also planning to give literature seminar assignments within project relevant areas to project team sub-groups.
7. *Project Workspace.* For future courses plans are made to provide a project workspace for each project team. This workspace is going to have both a virtual and a physical part. The virtual part consists of a web-based project portal and/or a PDM (Product Data Management) facility that has been tested during earlier years. In the project portal the team can work together virtually and manage their project. With the PDM system they can manage all their product related information. The physical part is a project team workspace in an office landscape equipped with tables, chairs, whiteboard, message board, computer network

connections etc. Each project team has access to its workspace throughout the whole project period. The teams also have access to prototype workshop facilities in close connection to their physical workspace.

8. *Student Assessment.* A possible way to increase the link between group and student achievements, student assessment, and factual grades would be to involve grading at certain stages of the project (i.e. the gates) and link these to the final assessment and grade of the completed project.

Conclusions

Our general experience from giving this multidisciplinary product development project course is that most students are much more involved and ambitious than is normally the case in "conventional" courses. The major tasks when administering this kind of course includes pulling together an appropriate amount of suitable projects (establishing more formal cooperation contracts with companies in the region is probably fruitful), to educate supervisors in project based learning philosophy, be clear about the fact that it is a project with a learning outcome as the major output and provide a stimulating environment where these project groups can work throughout the project.

In order to manage the change from ordinary project-based education to multidisciplinary projects one has to ensure the involvement of teachers from engaged disciplines, make the learning objectives for the different disciplines clear, and engage companies in this educational form.

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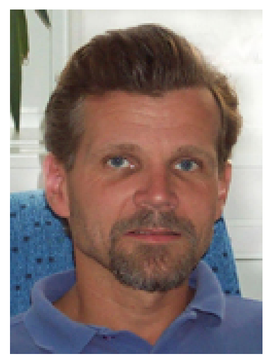

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