Project types and industrial collaboration in project-based learning

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INTRODUCTION

Project-based learning is important in engineering education as is makes the students test their skills in a real-life setting. We have organised project-based learning for software engineering students since 1991. Already in the early times, the projects were based on collaboration with near-by companies and other customers. This collaboration with external organisations, called *customers* in this paper, creates strong links between education and surrounding society.

In this paper, we report the experiences from our project courses. Especially we describe 1) how the courses have helped collaboration between students, teachers and companies, 2) the different categories for topics and goals of the projects. Based on the analysis, we outline a new project type, a *technology exploration* project.

1. DIFFERENT TYPES OF PROJECTS

This paper describes the experiences from two types of project courses: the engineering project [1], which simulates an industrial software development project outputting a working software product, and the innovation project [2], which provides the students a problem to solve and produces a demonstrator for the concept of solving the problems. The main difference between these project types is in the target setting; in engineering project quality of both the process and the produced software are evaluation criteria, while creation of new ideas is the main focus in innovation projects. Those types are described in the following sections. These projects last several months, but we acknowledge that there are also very short, a few days, camps or hackathons for similar purposes, but those are left outside the scope of this paper.

1.1 Engineering projects

Our engineering project [1] simulates industrial software development projects and combines the educational goals regarding professional software engineering. The first incarnation of the project was in the academic year 1991-1992. During 1990's, the course followed the waterfall model emphasising a plan-driven and document centric flow from requirements via design and implementation to testing. When agile methods became the common practice in the local industry, the engineering project followed the trend after some delay. The delay was mainly due to educational considerations. Agile processes emphasise the independence and skills of the team. We wanted to involve the teachers in the project in a guiding role, since the students are still beginners and the teams were formed for this course. An additional obstacle to an agile process was the need for customer involvement; the customers of the teams were external customers and in the case of agile processes they need to allocate more effort to communication with the team. Nevertheless, the practices moved towards agile principles, and the latest implementation in 2015 used Scrum [3] as the basis of the expected project model, while allowing some tailoring by the groups. This means that the process allows specifications to be built iteratively and incrementally in collaboration between the customer and the group. In this set-up the students concentrate in the customer needs instead of written specification.

Also, in 2015 we made the context more realistic by encapsulating the teacher involvement as a management framework based on company simulation, where the university personnel perform in company roles, such as CEO, QCO, and team coaches.

The project covers all phases from requirement analysis to quality assurance, and delivery of the developed software to the customer. The team members take different roles like programmer, user experience expert, and tester, but still their competence background is relatively similar.

Although the life-cycle models, processes and practical arrangements have changed the fundamental principle of developing a product or system that meets the needs of the customer have stayed. This goal has made work concrete and realistic.

1.2 Innovation projects

In addition to engineering projects our students have participated in innovation projects [2] by utilising the Demola network [4]. In these projects the students are given a problem to solve. The teams do not develop finalised software, instead they develop a solution to a problem, implement a demonstrator and work on aspects like commercialisation and business. Due to the wide spectrum of challenges, the teams are multidisciplinary and at least in our case consists of students from three regional universities. As the process aims at ideation and concept development, the starting point of the project is just a rough goal statement set by the customer. The student group is then assumed to proceed with ideation, assessment of the ideas, building of a demonstrator and pitching. The end result is not usually a working system, but a demonstrator or a prototype from which the customer can continue development.

The Demola projects follow a three-stage process [5]. The first one focuses on the ideation and concept formulation. In the second stage demonstrators are developed and ideas validated with the customer and users. Finally, the demonstrators are finalised and the results are packaged into a professional form where they can be assessed by the customer (and also potential investors). The process ends in a licensing decision where the customer can make a contract with the team about using the results in their business.

The process emphasises teamwork and close collaboration with the customer. The customer representative is ideally an active member of the team in creation and assessment session.

1.3 The differences and similarities

The two project types offer very different contexts and underlying assumptions to the teams. The main differences, more details have been reported for instance in [5] are:

- The innovation projects involve high risks and high uncertainty while the goals of the engineering project should be achievable with solid engineering work.
- The innovation project should apply creative thinking and discover something new while the goal in the engineering project is to meet practical needs.
- The teams in innovation projects are diverse and multidisciplinary while in the engineering students have studied computer or software engineering topics.
- The innovation project teams do much of their work in the premises of Demola in the same mental innovation space with other groups and start-ups, whereas in the engineering courses have no such close-up community feeling.

The size of the teams has been about the same, 5-6 students, and students are at the Master phase in their studies. Both project types have a real customer that they develop for. By default, the groups retain the intellectual properties of their work, but will form a contract with the customer about utilising their work either internally or commercially.

Companies expect something valuable in return of their participation, which in the innovation project is also monetary as they pay a fee to partly cover the operating costs of the working platform.

There are many issues in the execution of the projects and those mirror the issues new professional would meet in their first actual projects. In particular:

- Forming the teams, finding roles and deciding upon the work division. That is very similar to issues that any fresh team need to solve when formed.
- Handling cultural clashes when the team has members of various national backgrounds or members from different educational disciplines.
- Time and effort estimates of various tasks. This is challenging even to experienced professionals, so it is natural that student teams have these difficulties.
- Arranging time for meeting people when everyone has other activities. Especially software engineering students already tend to have full or part-time jobs.
- Communication with the customer. Young people do not have experience and self-confidence required for effective communication.

2 ANALYSIS

2.1 Impact of the project courses

The courses benefit students, teachers and customers in many ways. For students, project-based learning provides a platform for practicing skills required in real development work, be it more engineering or innovation in nature. In both types, the students learn collaboration, project work and working with a customer. The main difference in the learning outcomes is that the project course externalises academic knowledge from various preceding courses into action and thus into practical competences, whereas innovation-oriented projects expose the students to meet different new viewpoints, disciplines and practices and form an understanding about the whole they form by action, that is, collaborating in a team.

The students gain important contacts. Especially international students without local networks benefit from new contacts to industry. The customer companies also see the courses as a mean to support recruitment. The course improves the imago as an employer and sometimes the customers have immediate goals to discover new talents. The innovation projects, being close to local innovation infrastructure, offer students a route to form or join start-up companies. The contribution of the customers is also useful from teaching perspective. They play the role of customer and thus the students can learn how to work with a customer. In addition, the students learn useful practices and technologies from the customers. At the same time, many customers see course participation as a mean to support engineering education and working for the community.

In addition to competence and networking, the customers and community benefit from the outcome of successful projects. The customers see both project types as a mean to support product development that would otherwise be difficult to do. Some see especially the innovation projects as a catalyst for changing the thinking in a mature company that is too accustomed to its old thinking patterns. An innovation project can produce out-of-the-box ideas that can lead to completely new business.

A portion of the results of the projects is used immediately in production by the customers. Especially the software-only projects can produce readily usable results. Some projects produce technology evaluations that may provide essential information used indirectly by the customers. The third type of results are the products that the student groups decide to develop further.

Customer feedback is one metric of the success of education and we use it to further develop the course. For the engineering course, during the academic years 2014-15 and 2015-16, customer feedback has been collected systematically. The most critical question in the survey was: “Rate the group's overall performance (0-5).” The groups have been performing well from the customer’s perspective, with an average of 4,0 on the scale of 0-5 in 2014-2016. The customers have been pleased with the products delivered, but have seen deficiencies in how the groups work. That is exactly as could be expected and the groups are also expected to learn from the problems in their action. Nevertheless, customer feedback clearly shows that the projects give real value and with around 10 projects every year, the course has a real regional impact.

Students learn by various mechanisms. The parts with no difficulties provide a positive experience and validation of competences, but problems can be even more valuable as they provide an opportunity to solve the problems. Some projects may fail to produce a working product, but they can offer a great opportunity for self-reflection and deep learning.

As a summary, the project courses based on external customers have many great benefits to all stakeholders: university, students and customers.

2.2 Project topics

The engineering project topics are proposed mostly by companies, but also by public organisations based on guidelines given by the university. Customers are asked for topics that are challenging but reasonable for 5-7 students working during about 5 months. The outcome of the projects should be a complete and working systems – not just a demo. Customers need commit to regular interaction with the team and also provide any special tools and information. In addition, the topics should not include big secrets as team needs to discuss their work with the teachers and other teams.

In Demola the topics come also from external customers, but Demola calls for problems to be solved rather than requirements for a concrete system. Demola has also defined a legal framework that how the customer and team can utilise the results after the project.

The authors have acted as teachers in the project courses and have noticed that the diversity of project categories has become more diverse lately. The topic proposals were analysed for the last three years. Table 1 shows a summary for the topics that the student groups selected for their projects.

From the table we 1 we can see that vast majority (83 – 81%) of the project topics have clear product-related targets. The share of selected topics is smaller (23 – 72%). Technology related topics represent 19% of the proposals and 28% of the actual projects. The numbers show that students are relatively more interested in projects that deal with new technologies than in product-related topics.

We do not have similar access to the data for Demola topics, but based on our observations at one Demola site we believe that majority of the topics are related to a business problem to be solved, but there is also a substantial number of topics that want to explore opportunities provided by some new technology.

Table 1. Topic categories in engineering projects in three academic years 2013-16.

Category	**Definition**	**proposals / selected by students**
Technology exploration	Development task without product-related goals; just learning about the technology.	15 / 7
Technology development	Development task with some product-related plans, but those plans do not constraint the project work.	4 / 2
Product development	Development of an internal tool or sellable product. Usually, the goal is a prototype or an early version.	65 / 21
Product renewal	Extension or renewal of an internal tool or product	18 / 2
Sum		102 / 32

So, there are roughly three categories of projects: technology-driven investigations, product development and innovation. All these assume different course set-up and learning goals. In addition, they have different assumptions from the customers. Although product development topics fit best to engineering projects and innovation projects to Demola projects, sometimes the customers propose topics against that natural match. In addition, both our project course and Demola have received topics that are mainly technology exploration or development.

3 NEED FOR NEW APPROACHES

According to our experience and analysis described in section 2.2, a noticeable portion of projects under both projects types are in fact technology evaluations. They aim at evaluation of some new technology or tool with a real goal of providing the customer information on what the technology could do. Evaluations of that nature are important for the customers that want to utilise the latest technological opportunities, and the students are interested on those. However, they do not fit well to the current course frameworks. The technology exploration projects do not follow typical goal-related process; neither does it leave space for business-related innovation. This is especially problematic for engineering projects since the standard process models cannot followed and the promised learning goals will not be met.

We made a closer analysis to those technology experiments topics from fall 2015 that were selected by project groups. The main findings were

- Many projects had an artificial goal. The team was asked to develop an application that was not of real interest of the customer. It was just invented to be make the work look like development project, but the actual interest of the customer was in technology evaluation and the potential real applications may even be in a different domain. This weakens the customer feedback and directs the motivation of the team to a wrong direction.

- Technology exploration often involve new and immature technology. This means that the team might have a competence gap and neither customers nor teachers can give enough support.
- In technology exploration projects the teams are expected to try different approaches. Many of our development projects are iterative, but the iterations are expected to improve the understanding of real requirements. In technology exploration, iterations should be based different factors.
- The overall goal of most of the exploration projects was either finding an application or business opportunity, or finding a suitable technology for foreseen application or domain. The developed application as such did not have that much value.

The analysis shows that exploration projects do not match with the engineering projects whose goals are development of a system to meet customer needs. However, such technology evaluations are important for the industry and can allow the students a good environment for learning valuable skills. After all, the industry needs experts who can work with the latest technologies, assess them properly and produce information about their utilisation in a company's technology portfolio. Yet, we see that these evaluations should not be done in context where they do not belong, but need a special course type: technology exploration. That is why a new course type, technology exploration, is proposed to complement the other two. Its main characteristics would include:

- Clear definition of the goal. Can be experimental and analytical assessment of some technology, comparison of a set of technologies, or finding a suitable application area to some technology. This goal need to be agreed between customer, students and teachers.
- Research-oriented process. Instead of software development models like Scrum, the process need to build around research methods.
- Learning goals. Analysing requirements for a technology in a system, experimentation, analytical reporting and research methods.

This course type would support the creation of skills that are very valuable in product and technology development companies and in the emerging culture of experimentation-based development. The process is currently under development. Appendix 1 contains a preliminary process flow for three different variations of the process. Those have been reviewed by the engineering course personnel of which three have experience from product development, technology management or evaluation service provision and two additionally have long experience in course and curriculum planning.

4 RELATED WORK

[5] compared the learning context of Demola and engineering projects. Their work presented the background and motivation for the innovation projects, and they also reported how the working habits and course organisation differ. In this paper, we complement the research by analysing project topics and customer expectations.

Software Factories [6] are university laboratories that emulate real software companies with customers, deadlines and other real-life constraints. The concept has been implemented in six cities in three countries. The customer profile slightly differs in all those locations, but in general consists of local entrepreneurs, large companies, university research and open source communities. The existing reports give examples of the project types, but analysis of the project types is still missing.

[7] presents experiences of software project management education and suggests that the courses should relate to ACM/IEEE curriculum [8] and the PMBOK [9]. The courses described here are indirectly based on the ACM/IEEE specification as it influences the overall curriculum, but PMBOK has largely been superseded by agile ideas of project management.

Especially the technology exploration course highlights the combination of problem-based learning and project-based learning. [10] analyses the two types and their importance in engineering education noting that their definitions overlap. Key message derived from the paper is that both paradigms are needed in the development of the courses. [11] presents combination of both paradigms essential for the development of engineering skills that are effective for the sustainable development of society and also presents the knowledge and competencies achieved through using the paradigm.

[12] reports experiences from a project work course on one university, including the course implementation, project topics, development process and project challenges. They note the tendency for students to focus on customer's expectations and a need for a balance between that and educational goal.

[13] describes a project course distributed over several universities. The course used Scrum, war-rooms and other advanced project tools, and the focus was on global software engineering in contrast to the local setting in this paper. Another report on distributed projects [14] also provides some comparison to simultaneous local course.

[15] is an experience report of introducing agile methods in a project course. They found that teams who had an optimum balance of customer collaboration, use of agile methods, and technical programming ability had better productivity and product quality. The paper offers a deep analysis of three teams and a list of challenges for an agile project. They find for example the agile roles essential, which has been one of the development areas on our engineering course, too. They also underline mentoring, which is supported by our course having coaches for the teams.

Stakeholder management strategies and practices during a project course were studied in [16]. Those form an important learning goal. They note that each stakeholder’s ability to impact the project change over time. Thus, the project management team has to adjust the interaction in order to cope with these changes, implying an agile approach is needed not only on the feature planning but in other areas of project activity too.

Most of the project courses in universities are one or two semesters in length and have a restricted focus. The ME310 course in Stanford University is an exception, which, according to [17] is a year-long course and "cross between a senior capstone course, prototyping laboratory, and microcosm of Silicon Valley". The customers are large industry-leading companies and the course has international collaboration. What is interesting here is how the paper documents the changes in courses focus through decades from synthesis of engineering skills, immersion into design process, solving real-world problems, focusing on mechatronics, rapid prototyping, distributed teamwork, entrepreneurship, global innovation and finally foresight. Thus, the course mirrors the large-scale challenges in the industry. That dynamic changing of focus is essential for any course, but environmental factors dictate the possibilities for such approaches.

5 SUMMARY

In this paper, we describe how project-based learning can use external companies and other stakeholders as customers to make the learning situation more realistic. This industry-academia collaboration has several other networking benefits for the local community, too.

In the past, we have seen need for two types of projects: engineering projects and innovation projects. Both types of projects are executed in other universities too. In this paper, we propose a third type of project – technology exploration. This project type should include the elements of managed group work similar to other project types and industry-academia collaboration. In addition, it should have learning goals and a process matching the needs of technology exploration.

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APPENDIX 1: Basic expected research methods for the exploration types.

A. Assessment of technology	**B. Comparison of technologies**	**C. Finding suitable application area for some technology**
1 Specification of the basis		
Assessment context (given by customer or selected in colla-boration) – real business case, technological environment, users, other conditions Criteria specification for technology assessment Basic approach to assessment – experiments, other data collection	Assessment context (given by customer or selected in colla-boration) – real business case, technological environment, users, other conditions Criteria specification for comparison of the alternatives Basic approach to comparison – experiments, other data collection	Specification of technology goals customer's goals for utilising the technology (manufacturer, in product line, in what priority) Clarification of the key characteristics of the technology Concrete plan for the project
2. Data collection		2. Ideation of application areas
Information search about the technology, interviews	Information search about the technology, interviews	Brainstorming and other fuzzy front end techniques Rough concept development Selection of 2-3 areas for exploration and validation
3. Experiments		3. Analytical analyses for most potential areas
Experiment design Building of experiment environment Experiment artefact design and implementation Execution of experiments Evaluation of experiments	Experiment design Building of experiment environment Experiment artefact design and implementation Execution of experiments Evaluation of experiments	Analysis for the emerging usage patterns Risk analyses
4. Analytical assessments		4. Experiment planning, design and implementation
Assessment using analytical methods for non-testable criteria (such as architecture evaluation, reliability analyses, expert evaluations)	Assessment using analytical methods for non-testable criteria (such as architecture evaluation, reliability analyses, expert evaluations)	Experiment design Building of experiment environment Experiment artefact design and implementation Execution of experiments Evaluation of experiments
5. Overall evaluation		5. Comparison of alternatives
	Qualitative comparison and points- or pairwise comparison Conclusions and recommendations	Technical suitability Foreseeable designs and implementations Business analysis (optional)
6. Reporting and wrap-up		
Presentation of results, incl. demonstrators Written report of results Delivery of experiment materials to customer	Presentation of results, incl. demonstrators Written report of results Delivery of experiment materials to customer	Presentation of results, incl. demonstrators Written report of results Delivery of experiment materials to customer