AC 2012-4679: MUTUAL LEARNING EXPERIENCES: MECHATRONICS CAPSTONE COURSE PROJECTS-BASED ON SCRUM

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Mutual learning experiences – mechatronics capstone course projects based on Scrum

1. Introduction

The Mechatronics capstone course has been given at KTH Royal institute of Technology since early 1980s. The 2011 instance of the course involved 37 M.Sc. students, five companies and five projects. This paper investigates the learning outcome with both the students and the company representatives based on project collaboration during a period of nine months. The capstone course encompasses 18 ECTS credits, the equivalent of 12 weeks full time studies spread over a period from the end of March to end of December, with summer break from mid-May to beginning of September. The capstone course represents the semi-final step before the students' Master of Science degrees, followed by a master thesis project which, at KTH, is preferably done at a company, in the form of an internship resulting in a scientific thesis report.

During the 2011 projects, all five student teams voluntary choose and adopted the Scrum method for organizing their project work. In some cases, the company representatives had experiences from using Scrum or other agile methods in their software engineering groups, but Scrum had not previously been used in mechatronics design projects. In the capstone projects, Scrum applied to the student projects motivated the students to take a higher degree of responsibility in terms of project organization, overall and detail planning and dynamic re-organizations. In all cases the student teams voluntary choose to base their project organizations on Scrum after being presented with this opportunity by the faculty.

In this paper, results are presented of a study where the mutual learning outcomes have been investigated based on introducing Scrum into the capstone projects. These are related to the two types of actors in these projects; the students and the company representatives. The company representatives express slight changes in mindset after these projects, and express a greater understanding for agile methods in engineering design. The students express a greater understanding and preparedness for a future career in industry.

The challenge of today's capstone projects are not the specific technical competencies but rather organizational issues, as it has been experienced over many years. The projects are complex and based on knowledge and competencies in several fields, spread over all members of the student team (and faculty). At KTH, most resources in terms of course development and curriculum design have therefore been invested on topics such as product development, project organization, teamwork and mechatronics design methodologies. The faculty does believe that this is what's most urgent to include next in the curriculum.

Starting from March 2011, the faculty has transferred from organizing the students in the capstone course according to traditional organizations with student project leaders, division of responsibilities. Instead, encouragement is now put upon coaching the students in self-organizing dynamic teams using the Scrum approach. This has greatly changed the learning process within the capstone course by delegating the responsibility to the teams.

2. Scrum and agile methods for product development

Scrum is most widely used in software development as an agile development method and typically not considered for product development other than for software products. Scrum as a method emphasizes the empowerment of the individual, prototyping, quick and repeated feedback to reach the ultimate goal: faster delivery with a higher quality [1-4]. When applied to education in engineering design and product development, a parallel is identified to previous research of the importance of prototyping and quick feedback for the learning process [5]. In short, the factors that positively enhance learning within these fields are also emphasized in the Scrum method.

Scrum is an example of one of the first “lightweight methods” which is traced back to 1995. The Scrum method was originally suggested for “managing product development projects” but is today mainly used for software development projects [1-4]. The Scrum process is based on a few key principles, all somehow related to fast customer feedback, self-organizing teams and constant improvements. The product development team (the Scrum Team) typically consists of around ten members. One member is selected or elected as Scrum Master. The main role of the Scrum Master is to act as an interface between the Scrum Team and any distracting influences, which both implies to keep order in the Scrum Team and ensure focus but also implies to handle contact with, for example, the Product Owner. The Product Owner is a representative of the product to be developed, which can be an external customer or somebody with an interest of the final product [1-4].

The Scrum Team works in short development cycles, called sprints. Each sprint spans a period of typically a couple of weeks or a month. Each sprint starts with a preparatory task to define the tasks to be undertaken in the sprint and ends with a delivery to the customer or product owner followed by a session called the Sprint Reflection to discuss and propose improvements for next sprint. The product is defined in a Product Backlog (which replaces the traditional documents of requirement specification). The product backlog is agreed upon between the Product Owner and the Scrum Team and typically consists of use cases representing the final product. At each start of a new sprint, a Sprint Backlog is created as a subset of the product backlog in dialogue between the Product Owner, the Scrum Master and the Scrum Team. When defining the Sprint Backlog, emphasis is put upon selecting the features from the product backlog that creates most value for the product owner. During the sprint, daily Scrum meetings are held. These are typically very brief stand-up meetings where each team member answers three questions: what he/she did since yesterday, what he/she plans to do today and finally if the member foresees anything preventing him/her from accomplishing what he/she intend to perform within the foreseeable future [1-4].

3. The mechatronics program and capstone projects

The mechatronics masters' program at KTH is a full second cycle program according to the Bologna process [6] consisting of three semesters of courses plus a one semester-long master thesis project. The program mainly recruits students with a BSc in mechanical- or electrical engineering. The three semesters of courses conclude with a capstone course consisting of 18 ECTS credits (equivalent of 12 weeks of full time studies). This capstone course has been given since the establishment of the mechatronics program in the 1980s and has become popular with Swedish mechatronics industry. The KTH mechatronics capstone course has been presented in previous publications [7, 8]. The mechatronics program typically attracts between 30 and 50 students annually and recruits students globally. The studied course consisted of 37 students and engaged about ten faculty members. The 37 students were divided into five teams, from three to eleven students each. Each student team was assigned a company with an appropriate project.

4. The five companies and projects

In the following, brief descriptions of the five companies and projects are given, to provide a framework for the later analysis.

Company A is a large, multinational company in the medical technology field. The division hosting the capstone project develops and sells life support systems, primarily to hospitals and health care providers. The headquarters and the research- and development department of this division is located in the Stockholm area, within half an hour drive from KTH. The representatives of this company proposed a project as capstone project that involved the design of a new product that could be used together with the existing product line, a sort of support system for the existing product. This new product idea was not entirely within the core business area of the company, but considered as a valuable complement. In short, the product idea involved dynamic measurements of temperature and pressure, within a very short timeframe and high precision which put hard requirements both on the mechanical design of the support system as on the electronics involved for the measurement. The task proved to be more complex than first envisioned due to difficulties with non-stable temperature gradients and condensation and the student team spent quite a lot of time on instrumentation issues and analogue electronics.

Company B is medium-sized Swedish company developing production equipment for the electronics industry. The division hosting the capstone project develops equipment for surface mounted circuit boards and is the world-leader within their particular segment. The company is located close to KTH, within half an hour drive. In this case, the company had a product in their product line called “The T”. The T was an important complement to the other products in the product line, but had so far been quite unsuccessful due to its large size and price. Basically, the students were presented with the existing product, “The T”, and in a design brief the students were asked to redesign the product so that the size was about a fourth of the original size and the complexity vastly decreased (to reduce price). The product consisted of a feeding system for components to be handled by a surface-mounting pick-and place machine and involved handling large number of electrical components in two dimensions, with extremely high speed. In this project, the students spent the majority of time and effort on the mechanical design of the system including the motion control aspects.

Company C is a medium-sized Nordic product development company acting as consultancy primarily within embedded systems and industrial IT. The company is involved in the early stages of product design in a wide range of fields and for many different customers. In this specific case, Company C was recruited by a “third part” who hired Company C to design and manufacture a prototype of a machine to be used in a medical laboratory setting for the analysis of tissue samples. The “third part” was kept secret for the student team and Company C basically took the same design brief as being given from the third part to the student team. This company was also located within the Stockholm area. The project turned out to be very complex in terms of logistics, timing and data management as well as in mechanical design. The project included several motors, motion control in four axis, several pumps etc.

Company D is a small Swedish company with only a handful of employees. The owner of the company is an entrepreneur who has designed and built a unique kind of machine to process material (cut steel for example) that is sold worldwide in a handful of machines per year. The cost per machine is high and the company uses external consultancies and off-the-shelf control systems to implement most of the control of the machine. The entrepreneur/owner recently came up with a new idea for the machine which would enable many new functions and uses of the machine, resulting in a new business segment. The company is located in the greater Stockholm area. In this project, the company approached KTH to perform a pre-study and a feasibility study of the idea. The project defined for the capstone course was basically to re-build an existing machine with a new mechanical design of the core parts and add a new control system to support this new functionality.

Company E is an exception to the above, and is defined here as a “virtual company”, being an internal research project at KTH. It was however presented to the students with the same setup in terms of corporate sponsors, budget etc. The research project focuses on new technology for the vehicle industry and was currently focusing on hybrid drive trains. The research project have sponsored the capstone course on several occasions previously and had a history of mechatronics capstone projects. In this project, the design task was to design and implement a prototype of a hybrid drive train for use in a small vehicle, with the aim to make the drive as energy efficient as possible.

All five projects adopted the Scrum methodology, during the entire projects (from March 2011 to December 2011). All five projects delivered at least three prototypes according to the course requirements; one “critical function prototype” in May, one “semi-final”-prototype in October and a final prototype in December.

5. Student surveys

The data for this study was gathered in three steps; a team-wide survey of the student teams, an individual anonymous student survey and interviews with company representatives. In the appendix, seven tables of responses to student and team questionnaires are presented. These are extracts from the two surveys. The first survey was performed during the last week of the course, a few days after project delivery. This survey was performed team-wise and the student teams were asked a number of questions to reflect upon the learning progress during the entire project period. The reflections are documented in the appendix, without any editing. Two statements (questions) out of eight have been selected for this study. The statements in the first survey were followed up in the second survey. This second survey was performed individually and anonymously about two months after the project ended at the same time as the student grades were made official. This survey was undertaken online by 86% of the student population. From these two surveys, seven key issues were extracted for this study; two from the team-wide survey and five from the individual questionnaire. In the appendix, both the seven questions and the student responses are presented.

7. Interviews with company representatives

To complete the picture with the views from the company representatives, informal interviews were held where the industrial representatives’ experiences were discussed. Of the five companies, three interviews were held. In an attempt not to confuse them with the above presentation of the companies, they are here referred to as company 1-3. The other two companies where not interviewed, but a brief description on how the representatives acted and interfered with the students is provided. In the interviews and discussions with the company representatives, the view presented by the students in the two surveys is mainly emphasized. Representatives from company 1 in particular stated during the interview that they were positively surprised about the quality and level of innovation in the prototype presented by the students and that this definitely contributed to the work being done in the company. The same company however considered the Scrum-like organization not to be really advantageous and, while understanding and supporting the faculty’s motivation behind introducing Scrum, considered the methodology to be not that suitable for their own product development process. Basically, the company representatives considered Scrum not compatible with long lead-times associated with prototyping of mechanical parts.

Representatives from the second company went even one step further and expressed concern that the representatives were not allowed to interact with the students during the sprints. One representative wanted to be even more involved in the project and able to steer students away from potential pitfalls and thereby optimizing efficiency with the student team and reduce waste such as having students spend time on potential solutions deemed by the representatives to be dead-ends.

Of the three interviewed companies, the third company tried the least to adapt to the Scrum methodology but paradoxically most likely acted in reality as the most suitable. Representatives from this company clearly stated that Scrum is not suitable for mechatronics product development. The representatives presented a clear goal and list of requirements with the start of the project, and provided supervision and counseling immediately and at every request of the students, which meant that the students were able to apply a Scrum methodology per se. In this case, the student teams could treat the company representative as a product owner according to the Scrum terminology, and the representative acted very much like the product owner regardless of his/her intention.

The other two companies acted somewhat more downplayed against the faculty and the students. In both cases, company representatives provided a clear and realistic design brief and provided support and supervision anytime the students requested. In both cases, the representatives got very familiar with the student teams, visited often and expressed a great interest in the teams.

8. Analysis of questionnaires and interviews

In brief, the individual questionnaires show that the students indeed believes that Scrum can be good for mechatronics development projects (Table 4), but that it did neither make life easier nor harder in their capstone projects (Table 3). Table 5 shows that the students definitely considers themselves better prepared for future work in industry, while Table 6 and 7 shows that the students thought that the company representatives did learn (at least something) from working with the students (Table 6), but probably not from that the students worked with the Scrum methodology.

These individual responses can be compared to the team responses. During the reflection sessions undertaken by the student teams after the final presentations, a couple of important findings emerge. First, when the students are asked to define the top three advices for the next course instance, four out of five teams emphasize the need to prototype more and earlier.

"Prototype earlier", "Make simple prototypes" etc. Also, the need to set internal deadlines to enable better control of time is emphasized by four teams. Both these aspects are also emphasized by Scrum and the hypothesis is that the use of Scrum has made the student teams aware of the potential of these tools and activities. In the statements made by the students in relation to the "top three learning outcomes" we also identify many statements related to Scrum, project management and project organization.

When combining the interviews of the company representatives with the two surveys, and in particular in the light of the one question that deals with mechatronics product development in general, contradictory trends arise. Most of the company representatives considered Scrum not really suitable for mechatronics development, mainly due to the large lead-time of mechanical parts. The students however believes that, even though Scrum did not make their life easier (nor harder) that Scrum is good for mechatronics product development (there's at least a tendency towards positively favorable). The team-wide survey shows signs that the students appreciate the Scrum methodology and that this was beneficial for their learning and product development process. When, for example, several teams clearly points toward the need to do more and quicker prototypes, to shorten the cycles between prototypes and get feedback these are clear signs that the advantages of Scrum is both adopted and embraced.

The companies however, in the interviews, rather favored stage-gates and formal concept decisions. The difference between the students and the company representatives is, however, that the students are students and the representatives are not. Most of those had worked in their respective companies for quite some time and were considered professional in their profession (mechatronics product development). Where the students needed short iterative cycles to get feedback the representatives needed formal go ahead-decision. We do believe that this reflects the experience level of the engineer and that the two groups have different needs. Therefore, it is hard to judge whether Scrum is beneficial or not by asking these actors.

9. Conclusions

Of the representatives of the five studied companies, none had any prior experiences from agile product development other than from the software departments of the larger companies. Prior to the capstone projects, most of the company representatives expressed some concern toward the idea of organizing the project development work according to the Scrum methodology. Of the participating 37 students, none had any previous experiences from Scrum development even if some knew about the concept. When combining Scrum with mechatronics product development, as in the studied capstone projects, emphasize increases on rapid prototyping, quick feedback and incremental development in general. This is in contrast to more traditional mechatronics product development that often follows the Waterfall model or the V-model, with a stronger focus on stage-gate processes and formal procedures when moving from system design to detailed design for example.

Most of the company representatives expressed concern regarding using Scrum for mechatronics development. Most representatives had experiences from lean development and agile methods for software development and saw obstacles in applying an agile method to a combined mechatronics development project consisting of both mechanical-, electrical- and software development.

In conclusion, our evaluation shows that it indeed is possible to integrate Scrum in a mechatronics capstone course and that this makes the students better prepared for a future career. We have also seen that this prepares the students with a larger flexibility to handle the increased complexity in mechatronics product development and thereby enabling the project teams to deliver results faster, more reliable and with higher quality. Even though the company representatives initially were not sold on the idea nor expressed a great enthusiasm after the project, the students consider this advantageous. Since the methodology then does enable us to include pedagogically favorable methods such as self-organizing teams, fast prototyping, iterative cycles and quick feedback we consider this a step in the right pedagogical direction.

We do believe that both of the actors in this study were right; the company representatives did not consider Scrum especially advantageous for mechatronics development but the students did. Our conclusion is therefore that Scrum is advantageous for *learning mechatronics product development* but not necessarily for *doing mechatronics product development*. To be able to show the advantages of *doing mechatronics product development* we need to study the subject further.

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Appendix – questionnaire responses

Table 1 – top learning outcomes

Issue	Question 7: What are the top (three) learning outcomes from the course? (Stated team-wise, after final presentations)
Project A	• Important to have internal deadlines and milestones • It's difficult to create the overall system architecture • Try to avoid measuring temperature!
Project B	• Mechanical design in practice (tolerances and clearances) • Manufacturing (prototypes, mechanical, CAD) • Working in a big group
Project C	• Project planning is non-trivial • Integration and manufacturing takes time
Project D	• Stuff takes more time than expected • Hard to coordinate the different parties • Nothing works the first time you test it
Project E	• Low-level programming • Practical experience • First experience with Scrum

Table 2 – Top advices to next year's capstone course

Issue	Question 8: Give your top three advices to the next year's capstone course (Team-wise, after final presentations)
Project A	• Be sure that you have internal deadlines in the project • Keep integration in mind when designing all HW • Try to use the knowledge of experts
Project B	• If possible, build now! • Get a logic analyzer • If you think you will be done halfway to December, you will probably barely make it
Project C	• Start out SMALL, skip a lot of features • Put in more hard deadlines for yourself • Start prototyping ASAP
Project D	• Define a project with the teaching team and the company and make it unchangeable • Make simple prototypes • Plan to complete the prototype at least four weeks before the deadline
Project E	• Work in a team with more people than 3 • Divide the room from the start • Don't use Scrum for mechanical product development • Prototype earlier • Have ideas before going to talk with the teachers

Table 3 – Scrum in the capstone project

	Scrum made life much harder				Scrum made life much easier
Did Scrum make it easier or harder for you to work in the project?	9%	19%	41%	25%	6%

Table 4 – Scrum for general mechatronics development

	Definitely not!				Yes – absolutely!
Do you think Scrum is good for mechatronics development projects in general?	9%	16%	31%	34%	9%

Table 5 – Preparedness for work in industrial development projects

	I now have a greater understanding of how industrial development projects work	I gained additional technical knowledge	I learnt what type of industry I am interested in	I did not learn anything	Other
Please tell us in what way you are now better prepared to work in industrial development projects*	81%	66%	19%	0%	13%

* Students could select more than one option

Table 6 – Companies learning from students

	Not really	Yes – something at least!	Yes – they definitely gained new ways of looking at the problem	Other
Do you think that the companies learnt anything from working with you during 2011?	33%	55%	12%	0%

Table 7 – Companies learning from Scrum

	Not really	Yes – something at least!	Yes – we definitely got them thinking about how to organize projects differently	Other
Do you think the companies learnt something from your Scrum-like organization of your projects?	85%	15%	0%	0%