Practical Software Engineering Capstone course – framework for large, open-ended projects to graduate student teams

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Abstract. For students, capstone project represents the culmination of their studies and is typically one of the last milestones before graduation. Participating in a capstone project can be an inspiring learning opportunity or a struggle due various reasons yet a very educative learning experience. During the IT capstone project students practice and develop their professional skills in designing and implementing a solution to a complex, ill-defined real-life problem as a team. This paper reflects on organizing IT capstone projects in computer science and software engineering Master programmes in a Sino-Finnish setup, where the projects are executed in a framework provided by a capstone project course. We describe the course framework and discuss the challenges in finding and providing ill-defined challenges with meaningful real-life connection for project topics. Based on our observations complemented with students' feedback we also propose areas for future development.

Keywords: Capstone, IT student projects, project-based learning

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1 Introduction

During the past years, capstone project has been an important part of the curricula for studies in Information Technology (IT). Based on Merriam-Webster dictionary capstone means: "the high point: crowning achievement". Therefore, the project is the capstone of IT studies where the students use all their acquired skills and knowledge in culminating their academic experience. The main idea behind the capstone course is to provide an opportunity for IT students to demonstrate together, in a team, their true capacity to integrate and apply their knowledge and skills to a real-life (software) engineering problem.

Based on Rasul et al. (2012), capstone project is a unique type of learning experience for the students as in capstone project they mainly work in a self-directed approach and are expected to carry out various and numerous tasks related a large prob-

lem without structured approach provided by teachers. Naturally, the students are not fully out-of-support, but the idea is to transfer the learning process to be student-led instead of teacher-led. While the learning approach is different, also the assessment is based on different aspects. The consistency of the assessment practices of the capstone course needs to be ensured and clearly communicated to the students. As Mills (2007), Bramhal et al. (2012) and Gardner and Willey (2012) identified, the capstone assessment can include various tools from self- and peer-evaluation, process and product assessments, formative and summative assessments (such as the working process and the final outcome of the development), and students self-reflection of their learning in course-diaries/blogs.

The aim of this paper is to reflect on various aspects of organizing capstone projects as courses part of university degree programs. Structured student feedback collected at the end of the course records student experiences and provides data to discuss the relevance of various parts of the course. The students' feedback and teachers' observations are used to provide recommendations for iterative course development at the University of Turku, Finland. The University of Turku and Fudan University, China, have a strategic partnership of collaboration and provide a dual master's degree in Information Technology. Therefore, the two main student groups during the capstone courses were Finnish and Chinese students. In this research we analyse the master level capstone course feedback materials from years 2014 to 2018 and combine the findings with teachers' observations on the courses.

The rest of the paper has been divided into four parts. Section 2 deals with existing research and the theoretical dimensions of Problem-based Project-oriented Learning (POPBL). Section 3 describes the research design. Section 4 presents the findings. Section 5 includes the conclusions and introduces a few tasks for further research.

2 Literature review

Over the years, one of the most used approaches has been the teacher-centric approach, where the teacher has the full control and authority while lecturing at the front of the class-room. Senge (1996) wrote that most people expect to get answers from people above them, because they have grown up in an authoritarian environment and culture. Nowadays, this type of approach does not support the target to prepare students for their future workplace and face constantly changing working environment and requirements. Therefore, the responsibility of learning and own actions need to be pushed onto the students' side. Problem-based learning (PBL) is an example of a student-centered educational model (Barrows, 1996; Gwee, 2008, Savin-Baden, 2012) although based on literature PBL's effects are controversial (Dochy et al. 2003; Kirschner et al. 2006; Schmidt et al. 2009). In PBL approach, students' own learning process is placed at the centre of the educational process by supporting the students to construct their own knowledge, and to develop problem-solving and group work skills (Dolmans et al. 2005).

PBL and POPBL based capstone project is one implementation of a student-centric approach to provide opportunities for students to apply their content specific knowledge and workplace skills gained during their several years of studies (Dunlap, 2005; Lehmann et al., 2008; Dondlinger and McLeod, 2015). The focus is not only on technical skills but also on having the ability to identify non-technical aspects, interaction of those and propose possible solutions (Lehmann et al., 2008). Since the 1980s, the capstone type of learning approach has been part of universities' curriculum (Vanhanen et al. 2012). The capstone approach is commonly used, for example, in software development project courses where students design and develop software solutions in teams for external customers (Vanhanen et al., 2012).

Havelka and Merhout (2009) reported IT professional competences that IT professionals should have. In addition to technical aspects, many of the needed skills were non-technical and behaviour related. Havelka and Merhout (2009) categorized those skills under four categories: 1) Personal traits (passion, experience, conscientiousness, attitude, character, and flexibility). 2) Professional skills (organization skills, leadership ability, analytic skills, team-oriented, interpersonal skills, and problem-solving). 3) Business knowledge (business concepts, business process knowledge, and organization knowledge). 4) Technical knowledge (enterprise systems, development methods, application software, project management, production data management, architecture, infrastructure, programming, security & control, business intelligence, and communication networks). Practicing these competences is typically at the core of IT domain capstone projects' learning targets.

Reifenberg and Long (2017) wrote that students value the capstone experience. Based on Dondlinger and McLeod (2015) and Dondlinger and Wilson (2012) the capstone experience include challenges, but still the main approach has been favourable. The students reported to gain vital skills and competences, such as, learning new skills when applying prior knowledge; cultural understanding and new appreciation for people within their own culture; interaction and negotiation skills; and self-awareness (Dondlinger (2012). At the same time, Reifenberg and Long (2017) wrote of the capstone challenges, such as mismatch of expectations, information gaps, misunderstandings and challenges in cooperation among the capstone project team members.

In literature, it has been identified that one of the main challenges in capstone type of course assessment has been the tendency to focus primarily on written or product outcome (Todd et al., 1995; Jawitz et al., 2002; Lawson et al. 2014). This same challenge remains although it has been recognized that the main assessment criteria should be focused on skills developed during the project, such as teamwork, communication, life-long learning, and technical skills. Therefore, the final software program as outcome should not determine the passing grade for the course. Even if the written software does not work, the team can still pass the course if they have achieved the planned learning targets. The capstone course teachers can use a variety of tools and practices to get insight into capstone teams activities, such as self and peer-evaluation, process and product assessments, formative and summative assessments, and students' course-diaries/blogs (Mills, 2007; Bramhal et al., 2012); Gardner and Willey, 2012, Lawson et al. 2014).

Capstone projects can also provide students a valuable opportunity to be exposed to cultural diversity already during their studies when the students operate in a multi-national and multi-cultural situation. During the capstone project implementation the team members have to take into account member's national culture impact upon the whole team (Duran and Popescu, 2014). Morkos et al. (2014) conducted a comparative study between domestic and international students. They found that quite often the domestic students took the leading position, and the teams had to overcome the frustrating situations caused by cultural and language barriers by improving their communication and interaction skills. Morkos et al. (2014) pointed that the students may not immediately recognize the lessons they learned from the multicultural situation. The recognition of diversity related lessons happens afterwards.

While the quality and success of final product does not serve well as the main basis for assessment, when the intended learning outcomes emphasize improving problem solving and teamwork skills, the scope of a capstone project may reach to taking the results of the project into operation, providing not only evidence for direct assessment, but also a further viewpoint for students' self-assessment. In engineering education, CDIO has been adopted as a framework for curricular planning and outcome-based assessment (CDIO, 2018). CDIO (Conceiving – Designing – Implementing – Operating) framework, which is developed within engineering, stress engineering fundamentals set in the real-world systems and products, and cover the from understanding the problem to operating the built solution. In the late 1990s it was recognized that fewer faculty members had professional hands-on engineering experience and CDIO started as a reaction to associate engineering students back to the practice of engineering (Crawley, 2001; Edström and Kolmos, 2014)

Based on Edström and Kolmos (2014), PBL and CDIO target on broader learning outcomes emphasizing the process of becoming a professional, including both skills and personal development. A clear difference between PBL and CDIO can be identified: "*CDIO aims to align the intended learning outcomes with professional practice – and the focus on more appropriate processes for teaching and learning comes as a consequence of that. For PBL, it was the learning process that was aligned with professional practice*" (Edström and Kolmos, 2014). In other words, PBL focuses on rethinking the process whereas CDIO focuses on rethinking the outcomes. The spirit of the times when the approaches were developed has a direct impact: PBL was developed in the 1960s and 1970s (highly student-centered interpretation) whereas the CDIO was established much later and thereby includes more recent trends (such as, external stakeholder interest).

PBL and CDIO have mutual interest in, for example, problem-, project-, and design-based learning experiences and the lessons learned around organizational change strategies. Therefore, institutions can combine both approaches where the CDIO approach supports a structured process for learning outcomes, and the combination of CDIO and PBL pedagogy supports the development of learning experiences. Using CDIO approach in a capstone course has already been tested in higher education institutes. Two examples of the utilization of CDIO approach:

1)The principles and standards of CDIO were implemented in the MEng programme in Mechanical and Manufacturing Engineering at Queen's University Belfast (Armstrong et al., 2005). Armstrong et al. (2005) found that other courses need to be integrated with the capstone to provide support and add meaning to the topics covered

(i.e. constituted learning experience). The syllabus contains technical knowledge, personal and professional skills, interpersonal skills that are developed further during the capstone project (i.e. experimentation and knowledge discovery). Armstrong et al. (2005) identified that during the capstone project students mature and become more confident, and they develop their interpersonal skills.

2) In 2012, a new Capstone Innovation Project course based on the CDIO framework was piloted at Turku University of Applied Sciences (Kulmala et al. 2014). Kulmala et al. (2014) identified agile approach and Scrum to ensure successful project management and commitment. They highlighted the criticality of good project management skills: 1) to help students to move from the idea generation phase to implementation phase. 2 to commit the product owners and users to the development process, 3) to meet and interact with potential clients. Kulmala et al. (2014) found the assessment criteria defined in CDIO standards as a challenge to apply in some projects. Also finding the project customers relied on teachers' active role and it was considered should also students participate in the preliminary work to find and meet potential customers before starting the capstone course.

3 Capstone course implementation

3.1 The Framework

The software engineering capstone course is a mandatory course in the master level IT studies at the University of Turku. To provide it as a compulsory unit, timely linked to the degree program, and including all the degree program students, it has been organised formally as a traditional course in the teaching program. The course needs to have a clear structure, but at the same time it is important that the teachers only facilitate the students' learning, and the implemented activities are managed by the students themselves to achieve the expected learning outcomes.

One course takes three academic periods, about nine months, and the course is structured with regular predefined classroom activities (e.g., status reports, pitching, demonstrations). The focus of the capstone course is on designing and implementing a proof-of-concept level solution to a fairly complex real-world problem via practical test and try approach. The idea is to provide a situation that simulates various aspects from engineering working life phenomena in a safe environment that also allows failures. Sometimes learning from failures can be a better learning experience than learning from success. Based on our observation, teams that face failures during their project often analyse, identify root causes for their situation and actions, and even are able to take the needed corrective actions. Analysing the causes behind failures during a common class activity provides a viewpoint for students in other teams of these critical project factors.

Capstone project utilizes both PBL and POPBL methods and some elements from Problem-Solving Learning (PSL). As Sotto (2007) highlights, it is better that the students are quickly able to practice their knowledge and skills instead of spending sig-

nificant amount of time to understand the problem. By our experience the nature of problem, often also the field of its origin, determines how soon the team can start experimenting potential solutions. In this course, understanding the problem is given significant time, while however the project teams know from the beginning that they are expected to provide a working solution. They are encouraged to decrease the amount of uncertainty by quickly prototyping potential technologies and partial solutions as part of the design phase, thus the phases of CDIO are applied not separate, strictly one following the other, but overlapping and even sometimes repeating shorter cycles of the adjacent phases. To allow this to materialize, the project is given enough calendar time. The intended learning outcomes (ILOs) defined for this course focus on team working, communication and problem-solving skills. The students practice those skills with preselected project topics stretching out of their comfort zone, while also improving and widening their discipline-specific, in most cases technical, skills.

3.1.1 Project topics

The teachers spend a significant amount of time to discuss with potential topic owners and prepare the project topics beforehand. After running the course for 4 years, the concept is getting widely known and topics are increasingly suggested to the course (Step 1). Since the main idea of the capstone course is to provide open-ended problems to students, topic owners need to understand and commit to the course goals (Step 2) and accept that they cannot define the expected solution in details or give exact requirements to be implemented, rather describe the problem, user needs and aspects that have impact on the value of a viable solution. In the process of identifying and preparing topics for the project course the initial topic ideas are discussed (Step 3) and, with the incluence of teachers, often converted or reformulated from the initial idea the potential topic owner did present (Step 4), or even a new idea, more aligned with the course goals, comes up and is taken further in the process. Our experience is that only few suggested topic candidates are found totally unfit for the project course and once the course concept in working on ill-defined problems is explained, the topic owners mostly accept and even appreciate the more open-ended approach. To do a positive decision on taking a topic further (Step 5) the topic owner needs to commit to the project and allocate time to work with the team. The approved topics are presented to the project course (Step 6) to invite students to project team. A template of topic description is used to give new topic owners guidance on what aspects should be covered in the rather short description that is supposed both to raise interest among the students and appear possible with the knowledge the students have and can be expected to gain during the project. Forming the teams is explained later in 3.1.4.

The process of finding, validating and formulating project topics is summarized in Figure 1.

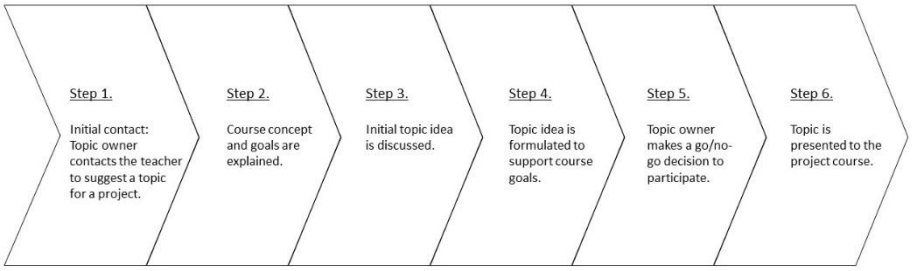

Fig. 1. Process of developing project topic

Within Fall 2014 – Spring 2018, 46 project teams have been formed to work on their topic. Of these, 12 teams worked on a topic provided by a company, 14 worked on a problem provided by university units representing other disciplines than IT, 4 teams created a product idea responding to a public hackathon or similar challenge, 1 team came up with their own product idea and 15 topics were provided and generated by the department of IT. Since the department offers also another master level course, titled Lean Software Startup method (Järvi et al., 2015), which focuses on the business potential and user value perspectives in developing innovations using the lean startup, the project topic ideas that are based on a students' own business ideas are channeled to that course. This division does not prohibit the capstone teams from considering commercialization of their project results, but business dimension is not systematically discussed as part of the course. The capstone project topics provided by the department of IT, in 2017 renamed as the department of Future Technologies, both serve as a buffer to accommodate the varying course sizes from one course instance to other and allow providing a range of topics that benefit from the full spectrum of modern technologies taught at the department. While in a way home-grown, these topics are chosen and defined so that there can be seen a real-life problem and application area for the solution to be built. Accepted topics typically do not directly relate to the research done the department, but utilize technologies known by a member of the faculty and relate to an application area of his or her personal interest, such as sports. The aim is, that while the topic owner in such case – being one of the teachers - speaks the domain language of the students, defining a viable solution requires understanding a phenomenon or need outside the domain of IT.

3.1.2 Attendance

The practice is that students enrol to the course beforehand. That way the teachers are able to evaluate the students' current level of studies. If the student does not fulfil the requirements (i.e. being master level students), the teachers can inform them to attend the needed courses prior taking the capstone project on coming semesters. Advance enrolment also provides indication on how many teams will likely be formed and thus the number of project topics needed for the next instance of the course.

The full attendance is mandatory, but the demand for 100% presence is adjusted, because students can have situations when they cannot attend (e.g. doctor's appointment or exam on other courses). During every lecture, the attendance is recorded with signature on the student list. That way the teachers can follow-up the attendance (which is one aspect of course evaluation) and also show that teachers care for students' presence. In case of a student missing multiple compulsory sessions, the student needs to agree on activities to compensate for their absence. This kind of social contracts are linked with professionalism (Vu, 2014) and applying those between teachers and students is good practice for working life. That way the students can practice the impact (positive or negative) of unspoken norms and rules.

One of the challenges in organising this course is timing. Typically, the Fudan students spend one academic semester, about six months in Finland. Still, the course takes longer, about nine months. This means that the teams built of students from both universities need to find ways to continue and finalize work even when located in two continents. At the early stage of capstone course implementation, it was found that the Fudan students considered their course related activities ended when they returned back to China and then the Finnish students alone had to finalize the project work. However, during the past few iterations this scheme of thinking has gradually been changed by planning and placing common course activities to the final stage of the project. Also holiday seasons of two cultures impact on the course. For example, the course that starts around January will be finalized around October. This means a summer break in the middle of the course in Finland, and Chinese National Day break in early Fall.

3.1.3 Lectures

The main teaching approach during the capstone project course is on active learning activities. However, due to the high amount of students (35-50 students) some traditional type of lecturing is also included to activate the students in the classroom to further process the topic inside their project teams. Every lecture focuses on a different topic related to the common stage of the projects by providing a short introduction to the students. The idea is to give "mental hooks" for directing their focus on digesting new topics and activities. The capstone course lectures include two parts. One part focuses on project management and communication specific skills. The second part focuses on team work and interaction skills. These lectures and hands-on practices provide the basic knowledge for the students to apply in their project team.

The course utilizes Moodle online tool to share and communicate course related materials. The materials are created by teachers, and there are no specific textbooks to be used during the course. This also encourages students to be active and write their own notes. Earlier research has shown that when students make their own notes, they internalize the topic better (Mueller and Oppenheimer, 2014). Earlier research indicate that slides can make students passive listeners or they focus on other activities (such as, Facebook, WhatsApp messaging, etc.) as they do not bother to make their own notes.

During the series of lectures the students will give several presentations, such as status reports, project plans and project pitch. The students get assignments during lectures to work independently and then during the next lecture they present the outcomes. Every lecture has a slightly different topic or focus to keep students motivated to work around the project with clear focus areas and deadlines. Although, based on observations, it has been noticed that many of the students are not motivated to listen other teams' presentations.

3.1.4 Project teams and forming the student teams

Based on experience collected from several capstone course iterations, team dynamics appears to be a core element of success or a serious hindering effect. Since student self-motivation is expected to be one fundamental element to successfully meet numerous project challenges, students' own interests are taken into account and raise of their motivation supported in the process of forming the teams. The process is illustrated in Figure 2.

At the beginning of the capstone course, teachers and topic owners present the prepared project topics to the class of students. After each presentation, students can ask questions about the topic (Step 1). On another all-class session the class is divided to random groups, number of groups corresponding the number of topics, and a group work is exercised (Step 2). In the workshop all students discuss in groups every topic, one at the time, and the discussion is guided with some questions provided by the teacher. At the end of the workshop, the class gets together and teacher goes through each topic, asking the class what kind of ideas or concerns had come up. Teacher also asks students, who are considering choosing each specific topic, to raise their hand. This workshop is used to both provide students an opportunity to discuss their concerns and interests in respect to the topics available, and create a situation where students discuss aspects of also those topics that may not have been raised their interest when initially presented. For the teachers, the poll at the end gives indication about the popularity of the topics and how the interest in the current class is divided between project topics offered. If a topic is found to be totally uninteresting to the class, it may be dropped out of choices. On the courses run, there has been one such topic on almost every other course.

After the workshop the students are asked to choose the three most interesting topics which they would like to participate in (Step 3). Based on the motivation letters the teachers will form the groups (Step 4).

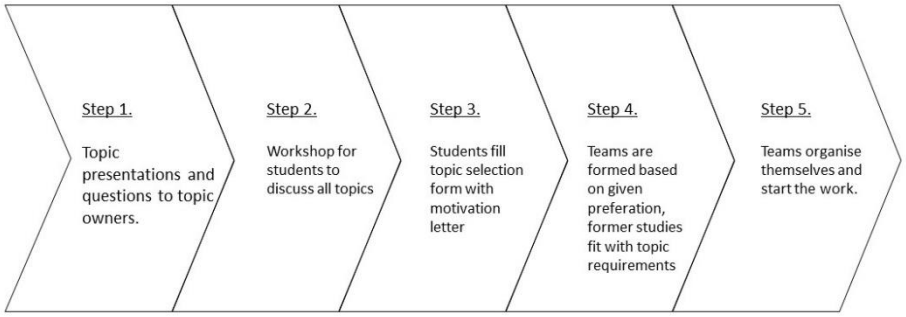

Fig. 2. Process of forming project teams

The students may not be assigned with the topic they primarily preferred. The teachers spend quite a lot of time to form the groups by reviewing students' prior courses and interests written into the motivation letter to ensure diversity and the topic specific skills needed to succeed. The team size can be slightly adjusted, 1-2 members more or less, to have the students to work on topics they have shown at least some interest, but the aim is that no student is assigned to work on a topic not listed in his motivation letter. The team size is taken into account when discussing the project target with the team and later when assessing the team performance.

Once the teams are formed, the team compositions are announced and the teams are expected to get together and organize themselves (Step 5). At this phase, some students ask for the reasoning behind their placement.

As the course participants consist of students both from the University of Turku and the Fudan University (China), the teachers ensure that every team is multinational. That way it can also be ensured that the teams practice their English language skills during their project work. At the same time, the students also learn to interact with people from different cultures and with way-of-working habits.

Since team working skills are in the core of intended learning outcomes of the course, the team size is normally aimed for minimum of four or five, ideal being five to six, but can reach up to eight students when the topic offers several areas to focus on, and thus provides a larger team ideas how to divide their work. However, larger team size can more easily accommodate "free-riding" type of behavior. In a smaller team members tend to take bigger responsibility for ensuring the overall success and they also support each other around the tasks and competences. In larger teams the division of work and responsibilities requires more attention from teachers.

Quite a lot of the students have working life background or they are even already working in industry. Having prior working life experience can help to excel in capstone projects and reach even more demanding goals, via deeper understanding of what they need to do and what is required from them. In other words, the students are able to fill the knowledge gaps of teachers' presentations with their own practical experience knowledge.

3.2 Project activities and course assessment

3.2.1 Topic owner interaction and project budget

All of the project teams have an external project topic owner, who is not a teacher on the course. The students interact with the topic owner, often seen as their customer, collect requirements and later present their solution proposal. Ideally the topic owner is an external/industry representative, but as noted earlier, research groups and researchers from the University of Turku have also been in this role. By default, the teams have very small budget that can limit their activities and technology choices. In the case that building the solution for a topic requires access to specific technology, topic owner is expected to provide this.

3.2.2 Project implementation

The project team assigns different roles to its members during the project activities. One of the key roles is that team leader, who usually is also responsible for customer communication. The idea is to learn to manage communication between the team and its project stakeholders.

Project planning is an important phase, because it shows how well and to what depth students have understood the problem and the requirements. The idea is to review and revise the project plan several times during the capstone course. The first plan is the first best guess, but the main lesson is that the project plan needs to be updated and re-estimated regularly. The idea is also to practice how to divide a complex tasks into smaller implementable entities. That way the students also practice how to schedule activities and what is the impact if they do not take the responsibility or ownership of implementing the tasks. Based on our observations we have identified ownership of the activities to be the most relevant success factor. If the students feel the ownership of the project, they are also willing to invest time and effort to the outcome and interaction.

The project teams also meet regularly with the teachers to discuss the details of their project. These sessions provide a tool for the teachers to assess the dynamics of interaction in the team and their potential need for support or advice to improve the situation.

3.3 Technologies and tools supporting learning outcomes

As the teams are allowed and expected to organise themselves, they also have freedom in choosing the tools they use, while the nature of the topic sets some requirements for technologies, e.g. specific type of sensors, to be used. Each team is required to keep a project repository to store their digital outcomes, and teachers are given access to it. Each team presents their choice of tools in their presentations in order to share experience and provide best practices within the course.

Used tools include common file sharing tools, such as Dropbox, Google Drive, etc., task boards like Trello, distributed version control systems like Git. These tools are used regardless of the technologies related to building the actual project result.

Technologies experimented in building the project outcomes have included various sensor technologies, app and web development frameworks, AI and machine vision algorithms and flexible computing platforms specially designed for learning purposes, such as Raspberry Pi. In some cases, a program-controlled device like a drone or model racing car has been used as the platform for the solution built.

4 Results and analysis

4.1 Students' feedback analysis

To evaluate how the course succeeds in guiding students to the intended learning outcomes we analysed the student feedback collected at the end of the capstone courses. The focus in this study was to analyse if the students report development in skills related to the intended learning outcomes on the course. The student feedback is collected by using online survey tool after the course. At the beginning of the capstone course, the assessment process including self and peer-evaluations was introduced to the students. After the course the students self-evaluated their own participation and contribution to their project. They also provide an evaluation for each of their team members. These self-reflected evaluations provide to teachers an insight into the team's operation and how the work load was balanced among the team members.

The students identified technical skills as essential to succeed in their capstone project. Three examples from the student feedback: "Technical support is really necessary", "The biggest problem was to do software project without actual programmers" and "We are all expected to understand and implement software programs. This was a huge issue in my group". Based on the feedback material it was possible to identify that technical aspects could be seen as potential discipline knowledge gaps and were one of root causes to teams' challenges.

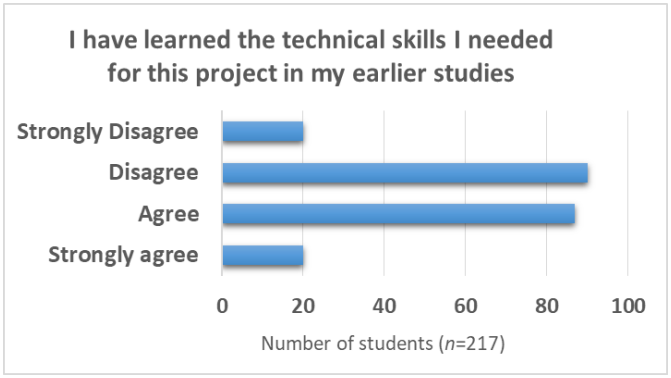

Fig. 3. Sufficient technical skills to succeed in a capstone project

The students identified various technical topics (Table 1) as development areas to better succeed in capstone project activities. Also the students' self-evaluation of their prior technical skills indicated that many students did not have the needed technical skills to excel in their capstone project (Figure 3).

Table 1. Students' self-identified areas for developing their technical skills

Algorithms and analytical skills:
- Algorithm and algorithm analysis
- Mathematical modeling
- Learning analytics
- Data-analytics
Programming:
- C/C++
- Java courses
- Object-oriented programming courses
- Web programming
- Python programming
Networks and Databases:
- Network knowledge
- Database technologies
- Network and Operation systems
Other technical skills:
- Cloud computing
- Software and HTML design
- Graphical design
- Robotics
- Geographical information systems and developing geo-informatics software
- IoT devices
- App development (Android or iOS)
- Version control

The new situation in which the students independently managed their capstone project and its activities caused question marks for some students. In typical approach teachers give more exact tasks and activities to be performed. However, the capstone project learning target is to practice team skills, take active responsibility on both defining and implementing project tasks, and the accountability remains on the student side.

Based on the feedback results some of the students expected more strict supervision and guidance from the teachers: "*I had a feeling throughout the course that there should have been more supervision that the team members were doing their job*", "*I wish we can get more supervision in the course, because our team was confused sometimes*", and "*Provide more detailed directions and motivating or pushing teams to start the project activities*". Yet, some of the students recognized that the supervision should come from inside the team, such as to be conducted by the project manager/ leader: "*There should have been more supervision that the team members were*

doing their job. However I think this should be something that is the responsibility of the project manager not the person managing the course. Maybe this should be emphasized more when talking about the role of the project manager". Some students also proposed to have a teaching assistant who would focus on supporting a specific team: "*I hope each project team can have one assistant teacher who is familiar with the project so that we can get the necessary help*".

Also motivation and interaction aspects caused some concerns. One of the key success factors to succeed in capstone project is student's own motivation. If a student does not have the needed motivation, it can affect the rest of the team. Few examples from the student feedback: "*Kick out unskilled and unmotivated students*", "*Capstone required a lot of motivation and hard work. Students of IT department are not usually very eager to make suggestions nor working without someone pushing them forward*." Some even proposed direct approaches to deal with unmotivated or non-participative team members who negatively impacted on their team working: "*I can only come up with two ways to improve motivation towards team working: either punishing students for not doing anything relevant or encouraging them to improve their teamwork skills*".

The interaction and experience sharing with the fellow capstone teams could provide opportunities to learn and cooperate. Sharing situations and challenges could provide a new kind of reflection window to team working: "*I would have some interaction session with other groups on how they are managing the project, what difficulties they are facing and what went so well, are we facing the similar kind of situations? This way we could figure out the common problems and complete the project better*". The communication between the different capstone project teams was very little and limited to the common all-class sessions. The interest to work together with other teams was identified: "*I hope we could have an open working atmosphere to exchange ideas and solutions with other teams*".

Based on the student feedback, the majority of the students reported skill improvements or they learned new technical or project management skills during their capstone project (Figure 4). As an example, the students reported: "*I got valuable information on project management and leadership and got to practice my presentation skills*". "*It is the first formal project course I have ever taken and most of the skills needed are new for me. So I have learned new things which makes me feel happy*".

Some students also identified that the capstone project was an opportunity to practice the skills and knowledge gained during the several years of studies: "*I believe the whole idea of a Capstone project is to employ the skills and competences learned in school and working life*". The students identified team working skills as an outcome of the capstone project: "*I liked the practical teamwork approach for common problems that required learning new skills and problem solving with different types of people. An eye-opening experience*".

The capstone project also provided an opportunity to learn new knowledge in another subject and thereby expanding the students' skills and working life capabilities.

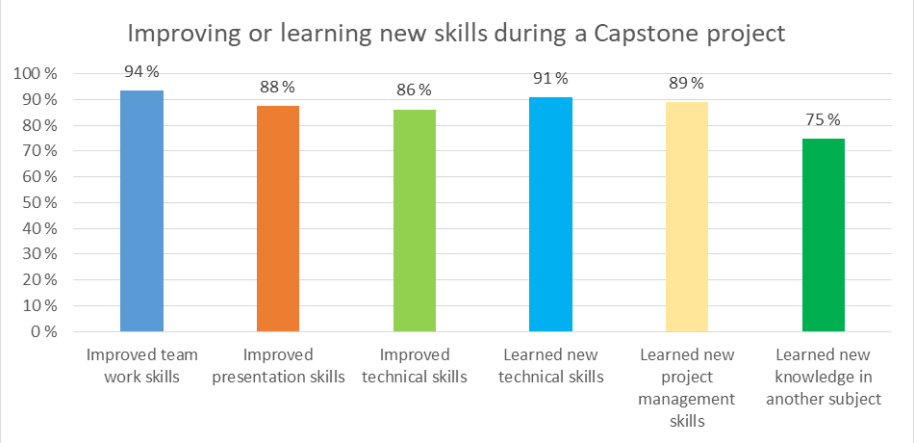

Fig. 4. Students' self-evaluation of their skill development after the Capstone course

4.2 Analysis and recommendations for further course development

Based on the student feedback, teachers' observations and hands-on experience, the following focus areas and recommendations for further development were identified.

Clarify the goals of capstone project experience. At the beginning of the capstone course, it is important to highlight to the students the opportunity to apply and deepen the knowledge and skills acquired in their studies and extend their academic experience by thinking critically and creatively during their capstone project. The capstone project provides a safe environment and an opportunity to demonstrate their proficiency in various areas and thus can be used as an asset on job markets.

Highlighting the importance of student commitment to the project and the team. Students' commitment has a key role in the success of a capstone project. This course is quite unique in making the students mainly responsible for their activities, schedules, team work practices, atmosphere, and deliverables. The teacher provides support, but the students have to take the initiative to raise the need for support and guidance. Still, some students try to push the responsibility back on teachers and stay passive waiting for more instructions. During the recent iterations of the capstone course the expectation for the students active role has been discussed more both at all-class sessions and when teacher meets individual teams. More communication and educating the learning method at the beginning of the course needs to be highlighted.

More focus on technical studies. The students need to gain the basic technical knowledge in their pre-capstone studies. Capstone project provides a tool for students to conduct self-evaluation of their current professional skills. For the university the success level of capstone projects gives input for planning how to teach these technical skills at right, early-enough points in curriculum.

Interaction between the capstone teams. A more low-profile interaction between teams could enable sharing and reflecting team challenges without the pressure of presenting the case to the entire class. Topics and situations encountered in capstone

projects could be discussed in small groups being a mixture of several capstone teams. The groups would share a summary of their discussion and reflected viewpoints.

Having assistant teachers and technical support. Quite many of the students experienced challenges with technical aspects during their project. Due to budget limitations, various practical exercises on earlier courses have been reduced (Majanoja et al., 2017). In the project students may also operate with technologies they are not familiar with and they need more technical support. Therefore, it is recommendable to have more resources for technical support and course assistants to support the capstone teams.

Expanding the course together with other faculties. While the majority of the students on past capstone project teams have been students of IT, providing a viable solution to most project topics could have benefitted from an interdisciplinary team. Engaging other subjects and faculties on IT focused projects could provide opportunities. To succeed, the project topics should systematically be developed together with other faculties. Linking IT and business students is a realized approach (e.g. Kruchten et al., 2011). In a multidisciplinary university such as University of Turku, several disciplines could ideally be involved.

5 Conclusions

The capstone project implemented in a team can facilitate learning on many aspects; team working and problem-solving skills, and extending graduate students discipline-specific knowledge and skills aligned by requirements and limitations set in real-life scenarios. From the vast variety of problems and challenges, choosing topics accommodating a sufficiently open, ill-defined challenge yet with a goal that can be defined and achieved using the skills in a team of postgraduate students, typically most of them still with little practical experience, while related to the technical domain of their studies, is a challenge itself. With the strong impact of student motivation present, the topic should appear interesting yet not overwhelmingly complicated to motivate the students in challenging them to take the project seriously and even give their best effort to it. The experience shows that some moderation is often needed to the topics suggested, initially but also while the project is in execution and the actual performance and capabilities of the team becomes evident.

The aim of a capstone project is to provide students a safe environment to practice their current knowledge and abilities, and experiment the diversity cultures, perspectives and even academic disciplines. Further target is to strengthen students' ability to think critically, communicate efficiently and use various technologies, both as project tools and as components of a viable solution. In addition, the capstone project provides a lesson about commitment towards social responsibilities, leadership, providing service to others, and how the lack of commitment affects the whole project team.

This study set out with the aim of describing and discussing the arrangements of capstone project courses in University of Turku, Department of Future Technologies,

and to provide recommendations for developing the course and its supporting curriculum. To form our recommendation the students' feedback was analysed and conclusion reflected against teachers' observations. The aim of the course has been in setting a framework that accommodates all IT master students to do a capstone project as part of their degree program in a timely way.

Based on the analysis it was identified that technical aspects cause significant challenges to students. Quite many of the challenges culminate around the students' limited practical programming skills and the capstone course currently as such does not have the resources to provide detailed technical guidance in all team specific issues. Therefore, more focus is needed on strengthening students' technical skills on their earlier studies before joining the master level capstone course.

The results of this study also indicate students' challenges to perceive their student-led role being in charge of all of the activities instead of following the traditional teacher-led approach. The change from rather passive receiver to active doer can be challenging. Students' prior working life experience has a positive effect on the whole team. Those teams are found to achieve deeper understanding of what they are required to do and more effectively fill the knowledge gaps with their practical experience. Thus, the teams with such earlier experience, are seen to reach higher excellence in the quality of their project results.

We acknowledge the limitations of this study as the results come from operations of only one university, yet serving a student population with two significant subgroups: students with their undergraduate IT degree from Finnish university system and students with comparable degree from Chinese universities. At the same time, however, the results are well aligned with the existing capstone research and discourse.

Future research should search for a systematic model for student assessment combining self-assessment, peer-assessment and teacher and topic owner viewpoints. Further, experimenting how to effectively support filling the fundamental knowledge gaps during the project is seen viable for the course execution. Also the relevance of the capstone project as a self-assessment tool for students' working life capabilities is a topic of further interest.

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