Challenges in implementing PBL: Chalmers Formula Student as a case

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INTRODUCTION

Over the past decades, there have been several calls for infusing engineering education with more active and collaborative learning methods, such as PBL [1]. Today, the acronym PBL refers to both problem-based and project-based learning as they share a number of principles. One such key principle is learning in an authentic problem situation, so PBL can be defined as "…an approach to structuring the curriculum which involves confronting students with problems from practice which provide a stimulus for learning." [2]. In PBL, small teams undertake a problem-solving task that requires them to identify knowledge gaps and acquire and apply new knowledge. Hence, the learning process is self-directed with the teacher acting as facilitator. Due to the nature of the engineering profession, where most of the work is performed in projects, project based learning seems to be the most applicable form in engineering education [1]. The design-build-test courses (DBT) are a form of project-based learning due to the focus on an end product, duration of time and the need of more formalised project- and team management.

35 years ago, a student design competition, Formula SAE, was introduced in the US, where Ford, GM and Chrysler initiated it aiming for more innovative thinking among engineering graduates. Although set up as a student racing competition, it includes more. The student teams need to – apart from the design, build, test and evaluation of a formula racer prototype – create a business case of production of 3000 items and account for their design, cost and manufacturing in presentations to industrial experts from all automotive fields. A total of 1000 points can be achieved and a third comes

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from the presentations, i.e. the static events. In other words, understanding of the context; engineering-, presentation- and teamwork skills are as important as the technical result, the car, and its performance on the track [3]. It has been shown that the educational value of Formula SAE is appreciated by students, faculty and industry stakeholders [4] and in many institutions it has been implemented as a DBT course in the curriculum, often as the senior project.

Previous research has demonstrated that faculty are aware of student-centred teaching methods but find it difficult to deal with unexpected issues that arise during the implementation phase and thus often return to traditional teaching methods [5]. It is therefore important to identify, describe and deal with different types of challenges or barriers that have a direct bearing on educational development. For senior projects, it has been shown that one challenge, and key factor for success, is the teacher's ability to act as a coach [6]. However, to the best of our knowledge, the broader description of challenges has not been done for the Formula SAE as a course.

In this paper, we use a case-study approach to identify and describe key challenges of implementing PBL in engineering education. Based on the first author's experiences of running and developing the course Chalmers Formula Student over six years, we identify several types of challenges: technical, organizational, student and faculty related. We also discuss how they were addressed. Being aware of these challenges and how to address them can improve success rate when implementing PBL to enhance student learning and provide a sustainable work situation for faculty.

1. CHALMERS FORMULA STUDENT

Initially Chalmers Formula Student, CFS, was run as an extra-curricular activity but since 2004 it is an optional course hosted by Mechanical Engineering open to all engineering students. The aim of the course is to provide possibilities for the students to gain knowledge and experiences of applied engineering work and prototype manufacturing in the context of the engineering competition. Important topics are system based thinking, communication and teamwork [7]. CFS is a 15 credits course and it runs on top of curricula during a full study year with a team of 25-30 students divided into subgroups. The assessment is based on a final report and presentation (35%) and project work and process (65%) reviewed by peers and the teacher team. The students also have to hand in a reflection on the project.

2. KEY CHALLENGES AND INTERVENTIONS

CFS from 2006 to 2012 was analysed to identify and group the challenges. This section presents the key challenges, summarized in the subtitles, and their interventions, highlighted in italics in the body.

2.1 Course and project – technical challenges and project infrastructure

To design and build a vehicle, especially in academia, can be a very complex and challenging task. Initial challenges concerned system-thinking, to learn the Formula SAE context, define the project, and secure resources for facilities. Once the technical tasks were defined in 2005 [7] and the team was set to 25 students with individual responsibilities, CFS was established as a project course. However, the non-technical responsibilities were not as clearly defined, nor the complete infrastructure, probably due to the lack of a holistic project perspective and project management methods.

2.2 The holistic perspective, addressing the full scope of project tasks

In the early years, each student was given one task, dividing the car into parts, which influenced the students' view of their responsibility in the project and negatively affected the project's holistic perspective. As a consequence, when all systems were assembled, no one had the responsibility when the car faced testing issues. This also affected the group dynamics, see 2.5.

To improve the holistic perspective, a more *structured project management* was introduced in the CFS07 team. The first changes included dividing the project into phases with clear goals and deliverables. Although used before, but not so explicitly, the phases Concept, Design, Manufacturing and assembly, and Testing started with a new planning night defining all deliverables and individual responsibilities. Each phase ended with a presentation to external partners and course reports.

A *team kick-off* was implemented the same year where the students got information about the competition and the course and had to create a team-based goal statement, top level, stating what they were supposed to do, when it should be done, how and why [8]. This goal statement became the team slogan. The kick-off has started every CFS team since then, although it has been further developed and improved.

A subgroup called *Technical Communication (TC)* was added to the CFS07 team to support the project management and coordination, to address static events deliverables from start and to improve internal and external communication. Thus the TC members had no technical responsibilities. TC increased opportunities of a well-defined project with controls and infrastructure [8] and good presentations and reports.

In 2008, the recruitment of the CFS09 team changed to further stress the importance of a holistic perspective and foster team commitment and joint responsibility from start. The project was set up as a *role-play* where the competition was presented as a customer, “Formula Racers Ltd”, engaging the engineering house, CFS AB, to produce a formula racer of a set target specification. The aim of the role-play was to change the students' and teachers' perception of the project from a “course” to a “company”, a real world task with external stakeholders, where CFS AB had to employ a cross-disciplinary team to deliver.

2.3 Student recruitment

When Chalmers educational organisation changed to BSc and MSc degrees, the CFS team consisted of 4th year and a few 3rd year students. However, due to difference in learning objectives, CFS could not be accepted as a BSc thesis, resulting in teams with mainly 4th year students.

At Chalmers, it was decided that all courses had to be part of a program. This meant that students from other disciplines did not think that they would be approved as team members, nor that CFS could be included in their master degree. This was a hinder to create multi-disciplinary teams. To facilitate the recruitment of a multi-disciplinary team, the *enrolment process* was changed in 2007 to include *increased project advertisement*, visits to lectures in different programs, an *information meeting* and a basic *application form* to be sent in. In the fall 2009, an *interview* was added. Basically, the students met briefly with the project manager (PM) and alumni students (later on Mini-managers). Issues discussed were workload, time restraints, study plan, previous experiences and skills in CAD and manufacturing, and maybe most important, the student's self-reflection on Belbin team roles [9] and preferences for technical subgroups and systems. The aim was to meet with all applicants to prevent biased selection of the students that were known to the examiner. As an effect it further developed the role-play, described in 2.2.

2.4 Project organisation, knowledge transfer and student learning

Since CFS was a course, the teams consisted only of students new to the project, rookies. A team with rookie students has no experience of the competition and no understanding of the complete project scope. Rookie students will therefore have difficulties taking leading or specialist roles from project start. This also adds to the teacher workload, see 2.6. To improve the knowledge base within a rookie team every year, without losing learning, was a constant challenge. In the early years, the course started with a blank sheet of paper, students making the same mistakes and learning from them every year. This can be argued to be the most fruitful environment for learning. However, it is the belief of the first author (and the students) that it is of outmost importance not to reinvent the wheel but to learn from past experiences and reach further than previous teams. Especially since there is an actual competition in the end where the gathered competence and knowledge of all CFS teams are tested. The competition judges approve of carry-over from previous concepts, if, and only if, the students are able to argue, justify and defend their design.

The addition of *alumni nights* in 2006 was the first attempt to address knowledge transfer. Previous CFS team members joined the team a couple of nights during the Concept and Design phases, answering questions and discussing ideas. The alumni nights exist still today, although in somewhat other formats.

Alumni nights were not enough though; the team needed input from professionals and faculty. In 2007, the work of gathering engineers and managers from industry and key faculty from Chalmers to form an *expert panel* started. Thanks to industry partners, realising the educational value of CFS, the panel was a reality from January 2008, when they attended the Design presentation and questioned the students thoroughly. The following year, expert panel nights were implemented during the Concept and Design phases, to enable review and feedback before the design was frozen. Over the years, more companies have joined the expert panel and now the team has a broad disciplinary support.

Innovative development of parts and systems was difficult to incorporate in the project, since the task to design, build and test a car in one year is more than enough for a rookie team. For further development of subsystems, two *spin-off projects* from CFS were launched as BSc theses in spring 2009. This facilitated recruitment and knowledge transfer; if willing to participate in next CFS team, the BSc students were invited to the competition at Silverstone, with the advantage of a few members in the new team with experience of the project and competition.

The outcome of the spin-off projects was great and the BSc students really acted as trainees in the project. Hence, a couple of *trainee positions* were launched in the recruitment of CFS10. The positions aimed for 3rd year students interested in the project. They had to take on a few assignments not linked to any subgroup. Upon delivery and will, they accompanied the team to the competition. Trainee tasks initially included PR, communication, webpage, newsletter, but were soon translated into more technical issues. The improved knowledge transfer between teams had positive effects on group dynamics, see 2.5

For the CFS10 students, the *course was extended* until September. The added requirements included a *project conclusion presentation* to the next team. The session was mandatory for both teams and scheduled two weeks into the new project. Initially the aim was to address the issue of high absence in the project after reporting the course, see 2.5, but the major effect was improved knowledge transfer between teams.

2.5 Group dynamics, multi-cultural issues, fatigue and lack of commitment

Large teams with students new to each other will experience group dynamics issues at some point [8] [10]. Due to the nature of the project and the workload during each phase, the team issues often surfaced after Christmas when the car was to be built. In the early years this stemmed from the flat structure and the lack of a holistic project perspective, see 2.2. Even in a flat structure the students will rank themselves in relation to each other, consciously or unconsciously, which influences team efficiency and group dynamics due to unclear roles and responsibilities [11]. Unclear roles led to diverse levels of commitment and divided the team into a core team and outsiders. The main difficulty was that the outsiders hesitated to engage in the project again, even though they were still committed. In CFS07 these effects were noted and the first interventions included *team management*, *team-based discussions, decisions and events, see 2.2*. This was, however, not enough, see below for further interventions.

There were many international applications to the CFS08 team, from China, India, Iran, Germany, France, and Spain. Previous teams were also international but not to the same extent. CFS08 faced multi-cultural challenges; on one occasion a fistfight between two students of different nationalities was resolved in discussion and by coaching involvement of the PM. The multi-cultural issues also showed as difference in language skills and communication, and how individuals from different cultures addressed, solved and communicated their solutions within the project. This affected deliverables and performance of systems. As a consequence, *team management methods*, such as the “Team flower” [8], were implemented. The aim was to measure project status as input to team discussions on how to address group dynamics issues.

The challenges in the CFS09 team were fatigue and lack of commitment, leading to conflicts and high absence. The signs showed after Christmas and peaked in end of May. Only 2-3 students attended testing sessions, leaving the PM to get the car to the track. The high absence might have been a result of the early course reporting, even though the project was not completed. Very few showed up for meetings, even fewer joined the test sessions although almost all attended the competition. To address the high absence, *course requirements were changed, see 2.4*.

The recurring signs of fatigue, communication issues and lack of delivery by Christmas time, made faculty discuss *team reorganisation* and in CFS11 *new subgroups* were formed halftime. A simple, yet perceptive, idea, since the organisation was adapted to the activities in each phase. The new subgroups created a need for all members in new roles that lead to increased engagement, improved system thinking, reports and presentations, and enhanced student learning. The team reorganised for the competition as well; a few defined roles developed into dedicated presentation teams, race engineer as drivers’ contact, and mechanical teams, together laying out the team competition strategy. The team reorganisation improved the holistic project perspective and knowledge transfer as well, described in 2.2 and 2.4.

2.6 Faculty challenges: two-hats, workload, teacher team and communication

Teacher time offered in CFS was underestimated since, in fact, it was two roles to fill; PM and examiner (“two-hats”). The “two-hats” issue surfaced clearly in the CFS08 team. The issue hindered project follow-up and communication since students who had trouble meeting their deadlines never told the PM in fear of a lowered grade, resulting in “firefighting” done by their teammates or the PM. When noted, the PM raised the “two-hats” issue and initiated a team discussion on how to prevent the lack of communication of failing deadlines, as they would always appear due to the nature of the project. As a result, the team stated “communication is key” and the PM implemented consequences; *a red flag system*, that could lead to a lowered grade if late deliverables were not communicated. The system functioned so-so, but stressed the importance of communication. In late 2010, one more senior joined and the long needed teacher team was a reality. First act was to split the project management from the examination eliminating the “two-hats” issue, clarifying roles and responsibilities enabling more work in different levels and areas within the project and course.

The ultimate challenge for faculty was teacher workload. In 2009, CFS had become an established project, although still fragile and dependent upon one teacher. Lively discussions on how to run the project in a sustainable way, meaning workload, financing, facilities, and support structures, led to new changes. The CFS10 initiatives had opened up to new ideas to address the teacher team issue: *make use of former CFS students*. Parallel with CFS11, the *Mini-management course* with its own learning objectives was announced open only to former CFS students. The course included project and team management, conflict types, and human archetypes. The students formed the CFS management and applied the theory in recruitment, composition and running of the new team during the Concept and Design phases.

The Mini-managers made a significant project contribution. After composing the team, been involved in the kick-off and running the first subgroup meetings, they implemented several seminars, lectures and workshops to support project technical start-up. The Mini-managers had in fresh memory what they had lacked in information and support the previous year and could design activities to fill the gap, improving the knowledge transfer, see 2.4. They acted as communication links, formally via weekly management meetings and informally by being present, hence decreasing teacher workload. After Christmas, when the Mini-management course ended, the new team was experienced enough to appoint their own subgroup representatives. Mini-managers hence created a team hierarchy, clarified roles and addressed the issues of the previous teams’ flat structure, see 2.5. Splitting management of the project between teachers and students challenged the communication however; the more involved, the better communication and coordination have to be. Student initiative is good and shows their ownership of the project. Yet, to keep a balance between acting alone or as part of a larger organisation with respect to its policies and regulations is a key success factor and sometimes difficult to teach students beforehand.

The teacher team faced internal challenges as well. Lack of communication, different aims and policies and the inability to sort this out, partly due to time restraints, poor leadership support and the focus on individual academic merits, resulted in a split teacher team by the end of 2012. Difference in aims surfaced mainly as a faculty discussion about focus on competition achievements versus students’ learning.

3 SUMMARY CASE – CFS 2006-2012

The technical challenges first encountered were followed by communication and team issues. Student recruitment, rookie teams and knowledge transfer resulted in high teacher workload and the teacher ‘two-hats issue’ appeared. With implemented project management tools, team building activities and the start of an infrastructure, CFS07 succeeded, as first CFS team, to finish all events in their first competition, ending in

12th place with 627 points. A couple of years passed with teams still finishing all events, ending at 12-15th position with less than 600 points, but constantly fighting the many challenges above and with teacher concerns of how to combine learning with good competition results. With an improved holistic perspective, a multi-disciplinary team, increased knowledge transfer and good group dynamics, CFS10 did a comeback; 11th place with 621 points by improved presentations and project management. This gave the idea of CFS as a multi-level project course. In 2010, the Mini-managers were implemented and the teacher team was supported by an extra senior which led to the first top ten position since 2003, 4th place, a win in Acceleration event and 721 points.

At last, CFS had developed skills in learning from past experiences. Via a good project organisation, benchmarked concepts and data-driven decisions, the team had the competence to make sophisticated designs and professional presentations and reports. This lead to 850 points and first place at Silverstone in 2012!

Consequently, addressing the diversity of challenges and focusing on the project in a holistic way, good learning and competition success will follow. With a strong focus on the competition alone, students' learning may suffer.

4 DISCUSSION AND CONCLUSIONS

A limitation of this paper is that it is based mainly on one teacher's experiences. However, the results are based on six years of experiences in development of the DBT course Chalmers Formula Student. Furthermore, at a workshop held by the first two authors at the international CDIO conference in 2014 attended by 18 teachers from different disciplines, some of these challenges were identified. Yet, the issues discussed mainly concerned course design, organisation, activities and especially assessment, which are the obvious challenges when first implementing PBL. The full scope of challenges will unveil after some time managing a PBL course, this is especially true for design-build-test (DBT) projects,.

Running the Formula SAE project as a course within the educational organisation has both benefits and challenges. The benefits being the educational value, that the student learning can be structured, monitored and assessed, and the project could act as the DBT experience in accordance with a CDIO designed curricula [12].

Challenges are: the holistic perspective of the project, the project organization, rookie teams affecting knowledge transfer and communication within extended teams, in turn affecting group dynamics, commitment and responsibilities. The educational organisation has an effect on the recruitment of multi-disciplinary student teams and the university organisation on the opportunities to create the required multi-disciplinary teacher teams. Lack of teacher teams leads to one teacher acting as both examiner and PM, contributing to the "two-hats" issue. All of these issues add to the teacher workload and creates emotional stress due to the lack of tools and support and the constant brooding on how to address issues that appear. Hence the most obvious conclusions are to facilitate the implementation and existence of multi-disciplinary teacher teams to address teacher workload. Furthermore, to implement multi-level project course organisations, i.e. let courses cooperate within the DBT project organisation, and increase the recognition of the large DBT courses within the educational organisation to facilitate student recruitment across disciplines.

The diversity of challenges described here highlight the complexity of implementing PBL in engineering education. To be addressed, most of these challenges require skills within team and conflict management, communication, coaching and facilitation. A toolbox of such skills is rarely a part of the academic faculty competence and it may be that teachers seldom continue with PBL [3] in their courses because they feel insecure, without tools, facing challenges in these areas. Support from university to improve and develop these skills and the ability to learn from previous experiences and best practice would help teachers [6] and increase the quality of PBL as well as faculty work environment. In this vein, Chalmers recently introduced an educational developer in the area of PBL, a position held by the first author, to support individual faculty members and other people with responsibility for educational development at Chalmers in finding sustainable ways to implement PBL.

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