SYSTEMATIC INTEGRATION OF PROJECT-BASED LEARNING IN AN UNDERGRADUATE HUMAN-COMPUTER INTERACTION COURSE: A CASE STUDY

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ABSTRACT

Project-based learning (PjBL) is a well-known student-centred methodology for engineering design education that encourages student-active learning through enhanced participation in the learning process and the development of increasingly important soft skills. In this paper, we report on our experience of transforming an interdisciplinary second-year bachelor level course in Human-computer interaction (HCI) into one where the educational concepts, principles skills and knowledge were bootstrapped onto the design process. We describe a PjBL approach to design-, prototyping- and testing phases in a student project involving Brain Computer Interface (BCI) technology, and how formative and peer feedback mechanisms and reflection were built into each stage of the project work. We review and evaluate the results with relation to the prescribed learning outcomes for this HCI course, report on the students' feedback on their learning experience, and discuss some of the benefits and challenges with PjBL in the context of a curriculum and degree programme that still favours traditional lecture-based teaching.

Keywords: Project-based learning, self-directed learning, assignment development, human-computer interaction

1   INTRODUCTION

As integral members of an increasingly complex society, engineers must have a mastery of both technical domain competencies rooted in science, technology and mathematics, as well as interdisciplinary skills of cooperation, communication, project management and life-long learning abilities in diverse multidisciplinary contexts. The boundaries of what constitute engineering knowledge and skills are growing and becoming increasingly difficult to define, challenging traditional educational lecture-based approaches to teaching and learning. Mills and Treagus (2003) [1] summarised some of the key common challenges in engineering education, which include the content-driven nature of many courses, the lack of focus on industrial impact, societal implications, and the need for teaching to be more student-centred.

In the past few decades there has been a general trend in higher education towards more student-centred approaches to learning, stressing self-directed learning, collaborative learning and learning related to practice. Project- and problem-based learning [2] are approaches that have the potential to provide students with sustainable and transferable skills that support the learning and application of domain-specific knowledge. Grounded in constructivism, project-based learning (PjBL) refers to the theory and practice of utilising real world work assignments on time-limited projects, organising the learning around the projects. Projects are complex tasks that involve students in design, problem-solving, decision making and give them the opportunity to work relatively autonomously over extended periods of time [2-6].

A human-computer interaction (HCI) course is especially suited to a PjBL approach as both disciplines harness cognitive mechanisms such as problem solving, memory and information retrieval and classification, inductive and deductive reasoning. These are integral to the study of HCI [7], thus providing students with an additional meta-cognitive perspective to their learning. More than a decade ago, Faiola [8] argued that "pedagogical models employed by many HCI and design programmes will risk becoming increasingly short-sighted if they do not provide students with knowledge domains that

can account for understanding design, social context, and business strategies in addition to computing." (p. 30). Culén and colleagues also argue for the importance of integrating design thinking in HCI to facilitate students' ability to work in multidiscipline teams in 'real life' situations [8] [9]. Whilst there has been significant progress in this regard, traditional, lecture-focused HCI teaching is prevalent.

Pedagogical goals and concerns, research and exploration were some of the key motivations for transforming what was a traditional lecture-based HCI course into one with PjBL at its core. Despite theories and a wider practice in later years, there is a lack of a universally accepted model of project-based learning, particularly as there is significant overlap with problem-based learning, making it difficult to assess what is and what is not PjBL [1] [11]. Going by Morgan's criteria of project-based learning [5], we adopted the Project Component model. Students were asked to relate their work to a 'real world' issue of their choice, which by its very nature required interdisciplinary thinking, and a strong focus on independent thinking and problem solving (contra the Project Exercise model, which is narrower in scope and focuses on the application of existing knowledge).

We had several broad aims for the course: (1) to develop critical thinking through reflecting on the (group) work as well as on the use of various HCI methods and techniques, (2) to learn to work in groups, (3) to learn how to learn in groups through the practice of self-directed learning.

2   COURSE PROCESS AND ACITIVITES

We reformed a traditional lecture based Human Computer Interaction (HCI) undergraduate course in the second year of an Applied Computer Science programme to fit a PjBL approach. The sample was composed of 28 self-organised groups composed of three to five students.

We focused on brain-machine interfaces, as the proliferation of relatively inexpensive consumer-grade EEG headsets has opened up new and exciting avenues of research and product development [12]. This was previously an extremely expensive and inaccessible technology. Whilst BCI technologies are still in a nascent phase of development with the consumer technology still largely too immature to be of serious practical use in daily life [13], the potential for low-cost mobile EEG headsets in the coming years is significant. The element of 'science-fiction' naturally lends itself to experimentation and the development of fresh ideas, motivating the choice of topic for this particular course.

We applied for university strategy funds earmarked for developing new pedagogical methods and received 170,000 NOK. This sum funded the purchase of technological equipment and for hiring guest lecturers and student assistants. We purchased a 3D printer, several arduino kits, Raspberry Pi kits, tablets and high-end PCs. We also purchased several consumer-grade EEG (electroencephalography)-based headsets, which were specifically for students to test / dismantle / reverse engineer / integrate into their prototypes. A key aim was to make the course 'hands-on' and facilitate the students' exploration of as many tools and technologies as possible.

2.1 Project description and deliverables

The context for the assignment as presented to the students was as follows: *For this assignment, you are required to design a neuro-wearable product based on the basic EEG technology underlying new low-resolution commercially available headsets. The goal is to take an idea and put it into practice by integrating the knowledge, skills and abilities you have gained from the HCI course into designing a brain-computer/machine interface product. This assignment consists of four parts and several deliverables.*

We placed a strong focus on what Helle et al [11] identify as a key characteristic of PjBL: the potential for using and creating multiple forms of representation. As part of the assignment, students we asked to consider how best to combine and present both the abstract and the concrete/physical aspects of their work in several media and formats. They had to make justified use of HCI methods in their projects, apply various methods and reflect on their usefulness for their project. The components of the final submission for the project work are described below.

1. Part 1: Brainstorm. A visual representation of their brainstorm or idea generation phase.
2. Part 2: Product design report. 2-3000 word report covering the use case or 'problem' the BCI product solves, its core features and constituent parts, the users and factors considered in terms of user experience (interaction design, usability and accessibility.)
3. Part 3: The prototype. A low-fidelity prototype in the form of, for example, a digital mock-up, a 3D print, a video simulation, or app.

4. Part 4: Academic poster. A visual representation of the main technical features of the product, with an emphasis on communicating the concept to a non-expert audience. The poster formed the basis of a 'mini-conference' showcasing students' work to the rest of the faculty.

Figure 1 illustrates two examples of the prototypes produced by the students. Figure 1(A) shows a 3D printed prototype helmet that would potentially allow cyclists to indicate the direction they intend to turn using a BCI interface. Figure 1(B) is a screenshot from a video demonstration produced by the students showing how a BCI could be used to control a toy car, as a proxy for controlling a wheelchair using only cognitive commands.

Figure 1. (A) 3D printed prototype bicycle helmet; (B) Video demonstration of a BCI-controlled a toy car

2.2 Peer evaluation and group feedback

The portfolio also included a peer evaluation form, which required students to (anonymously) assess the contribution of each of members in the group through a Likert scale of 1 through 4 (1=strongly disagree; 2=disagree; 3=agree; 4=strongly agree) on items such as punctuality, ability to meet deadlines, ability to co-operate, and the quality of work contributed. The peer evaluation also included open-ended questions designed to stimulated reflection on the overall experience of group work: (1) How effectively did your group work? (2) Were the behaviours of any of your team members particularly valuable or detrimental to the team? Explain. (3) What did you learn about working in a group from this project that you will carry into your next group experience? Students also completed a Group Work Contract, which, required them to reach an internal consensus on set of obligations and standards for participating in the group, including on what the penalties would be for breaking the contract.

2.3 Scaffolded learning

The role of the facilitator is extremely important in modelling thinking skills and providing metacognitive scaffolding. Organised teaching took the form of two-hour weekly sessions, composed of periodic mini-lectures and group activities. The purpose of the mini-lectures was to provide an overview of key concepts and themes within HCI, and more specifically, brain-computer interaction (BCI) research. The aim was to stimulate the students to use this scaffold to investigate and acquire knowledge of their own as it pertained to the specific problem they chose to tackle. This directed scaffolding provided the necessary foundation for subsequent self-directed learning. This is a key part of successful PjBL approach as it reduces cognitive load and allows the students to learn in complex domains [4] [6]. The majority of the scheduled teaching time was allocated to self-directed group work. We used a wandering facilitation model, rotating from group to group, adjusting the time spent with each of the groups and tailoring feedback according to their needs. A key focus was on metacognitive questioning that required students to explain their reasoning to the point where they realised that the limitations of their knowledge necessitated further research and critical reflection.

Students were given detailed grading rubrics at the beginning of the course for both the written report and the poster. The portfolio was graded as a whole and as a group; all members of the group received the same grade. The peer evaluation was not taken into account when assigning grades; it was a purely reflective exercise. The students provided the feedback and evaluation of the course before receiving their final grade.

3 DISCUSSION

Overall, we were satisfied with both how the collaborative process followed throughout the course and the project as well as the work the students delivered (no group received lower than a D grade). Students took responsibility for their own study and the process work documented in their deliverables and peer feedback showed an impressive degree of reflection with regards to both the course content and the PjBL approach. They described the work as challenging and meaningful, they appreciated working on what they perceived to be real-life projects and reported how learning one skill made it necessary to explore further and learn new skills, thus sparking intellectual curiosity and learning.

3.1 Student feedback

The students' feedback and general response was positive and reflected the openness, exploration and relative novelty of the course design: *"What I really liked about HCI course was that we had a lot of freedom when it came to the projects, and that we could develop our ideas and our concepts"* From another student: *"Having a project based on a field that is a bit "far out" makes you feel you are creating something innovative, even if it is only concepts and low-level prototypes you are working with"*.

This feedback was, however, not unanimous. Several groups expressed that the novelty of the focus technology, BCIs, made the test particularly demanding due to a lack of prior knowledge. The openness of the task and focus on finding their own way proved negatively challenging: *"What we have struggled with is that there are several different interpretations of the task, and several different interpretations of the feedback we have received on the guidance, thus there have been disagreements and in my opinion, we have ended up with the wrong idea that led to a worse end product."*

3.2 Assessing learning outcomes

Of the four principles for designing PjBL curricula defined by Barrow et al [3] ((a) defining learning appropriate goals that lead to deep understanding; (b) providing scaffolds such as "embedded teaching," "teaching tools," sets of "contrasting cases," and beginning with problem-based learning activities before initiating projects; (c) ensuring multiple opportunities for formative self-assessment and revision; and (d) developing social structures that promote participation and a sense of agency), evaluating the success of the first principle is the most difficult to address and evaluate [14]; we are confident that we successfully implemented the other three in the way the assignment was designed and implemented.

Deep content learning – the ability to understand and connect new content and apply it meaningfully with already learned content in new situations – is a key component of PjBL, but it is difficult to assess in a reliable and objective way due to a lack of standardised measures and poor reporting in the literature [14] [15]. The use of a novel HCI technology, largely unfamiliar to the students, allowed us to focus on their ability to articulate concepts in their own words and to recognise and draw on the relationships with knowledge from content provided during this and other courses. This is, however, confined to the work delivered for this assignment. The true depth of the learning, and whether it has led to remembering more content over longer periods of time, is an open question that we intend to address by following up the students at a later date.

Kirschner et al. (2006) [16] argued that unguided learning as included in PJBL is problematic in many contexts. The emphasis of practical application and learning through experience over teaching a discipline as a body of knowledge can come at the expense of learning the facts, principles and theories that comprise the discipline's content. In theory, students with self-directed learning can criticise their learning outcomes and detect topics not well understood or missed, but in practice this ability relies on well-developed metacognitive thinking (one of the things we aimed to train as part of this project). Failure to provide strong learning support for less experienced or less able students could lead to a significantly diminished learning experience. There is also always the danger with undirected learning that students acquire misconceptions or incomplete or disorganised knowledge, which when the focus is on the group, can be difficult for the teacher to become aware of and explicitly address. Feedback from one of the students explicitly illustrates the problem: *"We were aware that one of our members was not academically skilled or particularly independent. We tackled it in the way that we gave exactly explained tasks to the person concerned and expected that we would have to make corrections"*.

A related issue is that though using an 'exotic' topic as the foundation for the assignment was stimulating and motivating for the students, it set limitations on the depth and breadth concerning the curriculum.

Kirchner and colleagues' problematisation of diminished role of content in PjBL approaches has been robustly disputed by Hmelo-Silver and colleagues [4]. They argue that PjBL, which typically involves some form of scaffolded knowledge (for instance directed instruction), is not the same as unguided learning. In our case we provided direct instruction in the form of interactive mini-lectures. Also, PjBL-approaches address important goals of education that include not just technical content knowledge, but also epistemic practices and key soft skills associated with collaborative group work [4]. In the HCI course the practices consisted of fundamentals of design principles, user interfaces, prototyping and user testing.

3.3 Group work

The nature of the group work was a prominent theme in the feedback. Many of the students had worked together in the same group on other courses and this had a significant positive effect on how they tackled working on a challenging, open-ended project. A typical comment: "*We have worked together on all projects since the first semester and know each other well. Since we know each other's strengths and weaknesses we work very efficiently together, distributing workload and work in an effective way.*" This feedback was not expressed unanimously: "*Besides, instead of forming groups with friends, it's better to form a group with less-known people in order to not turn the group meetings into a playground.*" Whilst a small minority of groups explicitly expressed that unfamiliarity within the group negatively affected their experience, others embraced the challenge: "*You do not always know with whom or what you want to work in the future. It is therefore important to be able to adapt. In this project I have seen how important it is with acceptance and solution-oriented thinking. I dare to say that this group has made me a better person!*" Several of the groups, particularly those composed of students who have not worked together before, explicitly mentioned the importance of the Group Work contract: "*I learned that it is very important ... to set up a milestone and have deadlines and work according to the plan. How important it is to set up a group contract and sign it. If the rules are broken you can point to the contract*" and "*In general, I learned that establishing rules early on in form of a group contract made things a bit easier. I could see myself referring to the contract a lot more if I had been in another group that did not function so well*". The utility of the Group Work contract is something that we will specifically evaluate in future iterations of this course.

4   CONCLUSION

We are working to address several of the issues identified and to refine our approach for the next iteration of this particular course. In terms of content, we have considered focusing on a more mainstream technology to address the issue of perceived relevancy for the students. This will also lower the threshold for creating higher fidelity prototypes and open up for greater overlap between this second-year HCI course and the prototyping course these students take in their first year. We will also more explicitly address the issue of assessing the students' critical reflection and metacognitive thinking, both through an expanded project and course-evaluation, as well as through feedback and interviews with individuals and groups of students. One key improvement we plan to implement is an increased focus on investigating effects on the students' intrinsic motivation, which is closely linked with enhancing deep learning. We will also address the students' perceptions of learning outcomes related to the PjBL approach.

Implementing a PjBL approach in what was a traditionally lecture-based course presented a significant increase in workload, both in terms of preparing the project concept, and particularly the formative feedback and facilitation. Tight co-ordination and additional time and resources are required, not just within the course so that all activities are conducted effectively, but also with regard to the student's workload in relation to their other courses, which are likely to be taught differently and typically more traditionally. As students effectively set their own limits, there is a danger that they spend a lot of time on this type of course which is perceived to be a 'light' course with a large workload, contra courses like Programming and Databases that are seen as more difficult but based on more discrete assignments.

Despite notable limitations when it comes to explicitly addressing the extent to which deep learning took place, we are confident that we achieved the broad aims we set out with. Our experience is in line

with other reports on how PjBL approaches in HCI and design facilitates a hands-on learning process, fosters a spirit of investigation, innovation, creativity and motivation to learn, and generally improves the quality of the students' work [8] [9]. In addition, PjBL makes it possible to deliver both technical content and generic professional skills in a specialised course [17]. However, these approaches are most positively effective in enhancing deep learning when they are integrated into the whole curriculum, as opposed to implementation within a single course [15]. This is a significant challenge as it potentiates a fundamental rethinking and reorganisation of how courses are organised and taught – something we see is necessary if we are to meet the professional demands our students will face in the future.

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