Fostering 21st Century Skills through Interdisciplinary Learning Experiences

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INTRODUCTION

Digitalisation in developed economies has changed the skills required for many jobs. Preparing engineering students for the 21st century workplace is a challenge. Indeed, novel technology-rich work environments combined with ill-defined, open-ended problems require diverse teams to deal with them [1]. To prepare students, emphasis on design thinking, real world thinking and interdisciplinarity are key. However, we argue that many higher education curricula for engineers are severely siloed and rarely allow for such interdisciplinary educational activities. To address this issue, this article asks the following research question: *how can courses be effectively designed to foster 21st century skills*?

To answer this question, this article presents 3 case studies of interdisciplinary courses tackling 21st century skills. From these different case studies covering from 1 to 5 years, involving a total of 300 students and 20 educators, we extract 5 design principles to help future course designers and researchers. We used mixed methods to analyse the case studies. We relied on interviews with teachers, in-depth surveys from students evaluating the teaching (SET) as well as activity traces on online interaction technology used in the courses. We use a design-based research (DBR) approach, as reviewed by Anderson & Shattuck for educational research [2]. In this approach, we went through several iterations of each case study (one per academic year) to extract five learning experience design principles that can be reused by other researchers and practitioners.

1 RELATED WORK

The skills required for successfully navigating the workplace in the digital age are often referred to as 21st century skills. Such skills, rather than being specific to a particular discipline, are transversal. “Success lies in being able to communicate, share, and use information to solve complex problems, in being able to adapt and innovate in response to new demands and changing circumstances, in being able to marshal and expand the power of technology to create new knowledge, and in expanding human capacity and productivity” [3]. Binkley et al. [3] provide a framework based on an analysis of a dozen of different frameworks to help educators and course designers to think about assessing 21st century skills. They have identified four groups of skills: ways of thinking, ways of working, tools for working, living in the world.

Ways of thinking shift away from more straightforward thinking skills such as recall or drawing inferences towards higher order thinking skills, which require more focus and reflection, such as: (1) creativity and innovation, (2) critical thinking, problem solving, decision making, and (3) learning to learn and metacognition.

Ways of working include skills to manage interactions in a more decentralized work environment. Such an environment requires more elaborate (1) communication skills to convey information to others, as well as more astute (2) collaboration skills, to work more efficiently with others, who can also be from different intellectual or cultural backgrounds.

Tools for working cover new skills needs in terms of (1) information literacy in general, which include research on sources, evidence, or biases, as well as (2) technology literacy. These skills includes understanding how to effectively use digital and analog tools to support different work tasks, but also understanding their potential limitations and ethical implications.

Living in the world covers skills to live in a world which has become more interconnected and where it is not enough to be familiar with local issues, as actions can have global consequences. These skills include (1) citizenship, (2) life and career, and (3) personal and social responsibility – including cultural awareness and competence.

It seems unlikely that traditional education programmes are best suited to developing such attributes and this has, in a sense, been recognised for many years. In the late 1990s and early 2000s, the ABET and other accreditation requirements were reformulated so that they focused on skills or competencies rather than the titles of courses taken. This meant that programmes were no longer constrained to offer particular courses, and instead, they were free to approach competencies in a way that was, in the words of Ollis et al. [4, p. xiii] "freed from disciplinary blinders". This was also reflected in the development of a number of engineering schools, which aimed at better integration of social issues alongside technical disciplines as well as better integration of design thinking, and group processes within engineering education [5]. However, in many cases, e.g., [6,7,8], such interdisciplinary approaches continued to be seen as add-ons to already crowded curricula rather than substantively integrated components. In this context, Kazerounian and Foley [9, p. 762] for example, have argued that the dominant paradigm in engineering education teaches that there is a known correct answer and that the student's task is to find this answer as quickly and efficiently as possible. As a result, "factors (...) that impede creativity are far more profound and dominant in the engineering education than they are in sciences education and (...) in liberal arts education".

2 CASE STUDIES

Below we present 3 case studies of interdisciplinary courses at our institution that foster 21st century skills. Table 1 presents an overview of the course formats and population, whereas Table 2 illustrates how each course maps 21st century skills following the framework provided by Binkley et al. [3]. We briefly present each case study and highlight the most interesting characteristics.

Table 1. Case study overview

Case Studies	Format	Students in Year (background)	Lecturers
Case study 1: Social Media	14 weeks, 90 min per week (6)	Y1: 60 (60 STEM) Y2: 48 (48 STEM) Y3: 62 (49 STEM, 13 design) Y4: 51 (39 STEM, 12 design) Y5: 64 (48 STEM, 16 design) Y6: 66 (53 STEM, 13 business)	2 (engineering, Information systems), 3 guest speakers
Case study 2: Humanitarian Technology	14 weeks, 90 min per week	Y1: 23 (STEM) Y2: 57 (STEM)	2 (history, information systems), 4 guest speakers
Case study 3: Prototyping	Y1: bloc week (21 hours) Y2: 14 weeks, 90 min per week	Y1: 6 (3 business, 3 geoscience) Y2: 51 (35 STEM, 15 business, 1 political science)	3 (design, information systems, economics), 1 guest speaker

2.1 Case Study 1: Social Media

The social media course introduces Master students to human computer interaction methods relevant to designing social media platforms. The course is in its 6th Year and currently counts 66 students, (44 STEM, 12 business). In previous years, there were also around 12-15 design students in the class (in Year 6 the design students could not attend due to calendar conflicts). The course is divided in two parts. The first part consists mainly of lectures and ends with an individual mid-term report. Students are required to peer review 5-10 reports. The second part of the course focuses on teamwork. Students are asked to form interdisciplinary teams and design a novel social media solution using lean entrepreneurial methods (e.g., value proposition canvas, agile development). At the end of the semester each group is required to perform a presentation and deliver a report.

A Student Evaluation of Teaching (SET) was conducted in Year 5 with 59 participants (out of 69 students). The results show that most students are satisfied or very satisfied with the course (71%). Interdisciplinarity was appreciated by a large majority of student (87% report having enjoyed working with students from other programs) and 82% see how the interpersonal skills they practiced doing the project will be useful for working in an interdisciplinary environment. This was also reflected in the student comments. One of them noted “It was nice to meet and collaborate with people from [the design school]”, another wrote “Interesting interdisciplinarity!”, a third “It was cool to work with [name of the design school] students”. However, a few students raised some issues. For instance, one of the design student complained that she/he did not “like the moment when we assign groups by default because only one person from [the design school] by crew.” Another one had the impression that most of the work was done by the designer in the group. Indeed with the unequal number of students from different backgrounds, interdisciplinarity was enforced by assigning one designer per group. In the latest iteration this rule was relaxed. Peer review of student reports was also appreciated by most students (72% agreed that they received useful feedback from peers and 76% thought it was useful for them to assess the project of their peers). However in the first iteration of the course, students complained because the peer review assignment was too time consuming. A the time they had to review 10 two-page reports. We reduced the number to 6 subsequently.

2.2 Case Study 2: Humanitarian Technology

The humanitarian technology course introduces bachelor science/engineering students (57 in Year 2) to humanitarian technology. More specifically the course discusses how information technology transformed the humanitarian sector over the last ten years. It also shows how the technological revolution may cause undesired effects like marginalizing people who do not have the skills or the means to access information technology. The course is divided in three parts. The first one consists mainly of lectures with several guest speakers from the humanitarian sector. The second part exposes students to technology by doing hands-on exercises (e.g. analysis of satellite imagery using geographic information systems). The third part focuses on teamwork (groups of 5). Students are instructed to critically analyse a digital tool used in a specific context by a humanitarian actor. At the end of the semester, all groups present their project and deliver a report.

A SET was conducted in Year 1 with 18 participants out of 23. The SET showed that 72% were satisfied or very satisfied with the course. Students’ feedback highlighted the “living in the world” perspective of the course: "I find this course really interesting, because it addresses really important current issues. The fact that guest speakers came during the course, made it even more interesting". Despite mostly positive comments there was some demand for more “debates between participants” as one student noted. In Year 2, this issue was addressed by including more hands on activity and debates. For instance, we used a digital interaction system to gather opinions and trigger face-to-face debates. A SET conducted in Year 2 with 46 students out of 57 showed an overall higher satisfaction level (85%) and a high satisfaction for the new digitally mediated debates (83%).

2.3 Case Study 3: Prototyping

The prototyping course introduces bachelor students to design thinking methodologies. After a pilot conducted in Year 1 with 6 participants, Year 2 counts 51 students (35 from science/engineering, 15 from business, 1 from political science). The course is centered on teamwork (groups are interdisciplinary and formed by the lecturers). The core task of the teamwork is to design a prototype to nudge behaviour towards a more sustainable campus. The particularity of the course is the fact that in every lecture there is a majority of time

devoted to short time-boxed hands on activities preceded by short theoretical introductions. Hands on activities include creative tasks such as ideation, analytical tasks such as defining a user journey map, or evaluation tasks, such as providing feedback to other students. The heterogeneous nature of the audience (i.e. affiliated to different schools/sections) implies that students find it hard to work together outside of class so that time spent together in class therefore becomes even more valuable;

A SET was conducted in Year 1 with all 6 students. In addition an in depth observation by two pedagogical counsellors was conducted and the experience was documented. Overall the workshop was deemed useful. Participants found the iteration loops and creativity involved in the process particularly interesting “being able to use a number of creative tools allowed me to regain my old-world imagination and, automatically, ideas and concepts that I probably would not have found without them." It should also be noted that there was an interpersonal conflict in one of the groups, which was resolved after the intervention of a mediator. Time pressure was both regarded as stimulating but also as something preventing reflexivity. A SET evaluation in Year 2 with 30 participants out of 51 showed that 89% were satisfied or very satisfied with the course. Further, 96% agreed or strongly agreed with the usefulness of giving/receiving feedback from fellow students; 90% agreed or strongly agreed with the usefulness of having hands-on activities. Time pressure and interdisciplinarity were also generally viewed as positive (74% and 80%) but it also met with some level of disagreement (10% and 7%). It should be noted that in Year 2 there was also an issue with a group that had to be split up and members reassigned due to conflicts.

Table 2. Mapping between case studies and 21st century skills

21st century skills (Binkley et al 2012)		**Case study 1: Social Media**	**Case study 2: Humanitarian Technology**	**Case study 3: Prototyping**
Ways of thinking	**Creativity and innovation**	Collective Ideation	Assess innovation	Ideation, sketching
	Critical thinking, problem solving, decision making	Peer review	Peer feedback Critical ICT assessment	Peer feedback, user-centric, test driven
	Learning to learn, metacognition	Agile process	Connecting information and arguments	Agile process
Ways of working	**Communication**	Presentations, report	Presentations, report	Presentations, report
	Collaboration	Teamwork	Teamwork	Teamwork
Tools of working	**Info. literacy**	Evidence-based design	Research on sources	Evidence-based design
	ICT literacy	Social media design skills	ICT in crises	Maintain a blog
Living in the world	**Citizenship**	Social Media	Humanitarian Issues	Sustainability
	Life and career	Produce results	Produce results	Produce results, Manage Time
	Pers & soc. resp.	Interdisciplinarity	Interdisciplinarity	Interdisciplinarity

3 DESIGN PRINCIPLES

Based on the best practices evaluated iteratively in the case studies described above, we present five design principles to help design learning experiences for the 21st century.

3.1 Content that matters

Learning experiences should be built around content that matters, societal issues and real world thinking (Living in the world). Our case studies underline the fact that societal issues such as humanitarian work, or sustainability can be transversal goals for graduates who are particularly engaged when confronted with addressing important challenges. Such topics require thinking beyond one's own expertise to weigh diverse competing knowledge claims and to make decisions without clear right answers. It should be noted that in the case studies the content gives the context of the course, and the real learning outcomes are based around the process (whether creative, critical, or entrepreneurial).

3.2 Timeboxed hands-on activities

Learning experiences should integrate active timeboxed hands-on activities. Involving students through active learning activities has been found to be an effective way for them to learn (Ways of thinking) [10]. Students should be introduced to adequate tools to support hands-on activities, whether low-tech, such as visual canvases to structure ideas, or high-tech, such as online platforms to share resources (Tools for working). Our case studies showed that time pressure can make the course more enjoyable, but it should be well scaffolded as it can potentially frustrate some students. Integrating documentation and reflection in such fast pace activities is challenging as students can find it hard to pause and reflect upon their learning.

3.3 Meaningful peer interaction

Learning experience should take advantage of the presence of students to foster peer-to-peer interactions and peer instruction (Ways of working). Our case studies show that interaction between students is appreciated. Peer review can also be used successfully, whether of assignments or informal deliverables. Furthermore group interactions around brainstorming, sharing opinion, understandings or debates, can be effective when scaffolded adequately. To do so, there can be a range of tools that can be used (Tools for working), from low-tech options such as stickers to vote, sticky notes or drawings, to high tech options such as social media apps or shared online artefacts.

3.4 Build interdisciplinary teams

Learning experiences should include students from different disciplines and bring them to work together in interdisciplinary teams (Living in the World). Our case studies show that working in interdisciplinary team is appreciated by students, but can present difficulties. The difficulties of working in interdisciplinary context range from communication differences, often referenced to as "he/she does not speak my language", to change in perspectives and attributing values and importance to different things [11]. Thus, it is essential to scaffold these interdisciplinary groups effectively. For instance providing students with outside mediation or better yet with tools to identify and resolve conflicts.

3.5 Bring perspectives through a diverse teaching team

Learning experiences should include diverse teaching perspectives. Along the maxim "practice what you preach", it is important that students understand that interdisciplinarity is not something that only comes from them, but is also practiced by the teaching team. For teachers, to be confronted to the perspectives of others enables them to get a sense of what

students are experiencing. Including external speakers is one way of bringing different perspectives, another is to co-teach courses in interdisciplinary teams.

4 CONCLUSION

Designing interdisciplinary learning experiences to support transversal 21st century skills is challenging and such skills cannot be expected to be developed in full through a single course. In this paper, we drew five principles to help design diverse learning experiences on three case studies, which spanned over several years and included 488 students. With the advent of online education, it is crucial that universities rethink the added value of bringing students to campus.

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