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Online Course Design Using Iterative Workshops on Computer-Supported Collaborative Design for Engineering Design Students

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Abstract

Based on observations of global design classes at different institutions, students selected technologies without justification for the suitability of the technology to support their collaborative design activities. To best support students in their collaborative endeavours, a short online course in computer-supported collaborative design was developed. The process of the creation of the short online course was unique using students' identification of their gaps in knowledge during workshops, iteratively over three years to develop a complete educational experience. Workshops were conducted with students to identify gaps in students' knowledge that were addressed at future workshops, by filling these gaps and conducting the same gap finding activity the researchers can identify if these gaps can be filled through an educational intervention. Surveys were used to evaluate the success of the development of an online course in Computer-Supported Collaborative Design (CSCD). The method for the development of the short online course was logical and successful based on feedback from students during surveys. The outcomes of this method can have implications for those developing novel courses in familiar teaching environments or new digital media. This research has identified the interventions required to prepare students for global design projects in a novel way. Lessons from this research will support other educators to consider their course development practice

Keywords

Course design, Higher education, Multidisciplinary, Virtual teams, Collaborative design, Student learning experiences.

Introduction

Collaboration is commonplace in engineering design education with the trend towards projects and problem-based learning. Learning-by-doing, Active learning, Experimental Learning and other empirical based constructionist theory learning mechanisms have been critically influential for how engineering is taught in the 21st century (Williams, 2017).

In recent history there was a trend in engineering education to introduce abstract conceptualisations taught within lectures to transmit knowledge from professor to learner. However, this has commonly been replaced with interactive learning interventions that enables experiential learning (Sole et al., 2021). Lab and tutorial work was frequently used to strengthen understanding of the learner and confirm that the learners understand the concepts that the professor is teaching (Christie & de Graaff, 2016).

These educational theories document a trend towards models of learning where active participation justifies experience, reflection and abstracting such as is theorised in the Kolb cycle of experiential learning (Kolb, 1984). Through active engagement students are building real-world skills that future engineers require. This is not simply the facts and physics that govern our reality, however, this is the analytical and critical thinking skills essential for complex challenges in modern engineering. The skills built are how to think about these challenges, students require training to develop these skills (Dewey, 1910).

From early theories of philosophy, Aristotle lead the way for theories of Empiricism, "anything learned is gained through interactions and associations with the environment" (Schunk, 2011). Knowledge is developed from interactions with the world, and these interactions can build to form complex ideas. Fundamentally, this is to reflect that the learner is involved with the learning process. The learner creates meaning from the experience (Bednar et al., 1992)

For engineering design in particular, this is reflected in the development and learning of skills that engineers acquire. There has been a noticeable change in the way engineers are educated and a focus on softer skills within engineering (Sole et al., 2021).

Modern Engineering Design Education

Changes in education are impacted by the tools and technologies available. As evidenced by the accelerated change to online learning as a result of COVID-19 (Fleischmann, 2020). An acceleration in the transition to the use of technology to support engineering design education and engineering design in practice. However, this change was prefaced with motivations towards online learning throughout the 2010's. The emergence of Massive Open Online Courses (MOOCs) (Sezgin & Sevim Cirak, 2021), remote learning courses (Balamuralithara & Woods, 2009), multi-campus learning (Sielmann et al., 2021) and improved Learning Management Systems (LMS) with increased functionality for multimedia (Hussain & Jaeger, 2018) have all contributed towards online learning as an equal experience to traditional in-situ learning on campus. In certain cases, there are examples of how online learning has gone beyond the learning experience that can be facilitated in a traditional environment (Smart & Cappel, 2006; Luo, 2019; Qiu, 2019; Yu et al., 2018).

With increased opportunities for learning comes increased opportunities for complexity in the learning experience. This has been observed in the Global Design Projects (GDP) class since its inception in 2007 with more robust studies on the impact of technology in supporting students learning experience since 2015. Since 2010, it was observed that students would choose to use social network sites and mobile devices to communicate with distributed student team members from other partner Universities located in London, Malta, Budapest, Finland, China, Australia, New Zealand, and the USA (Brisco et al., 2016). This practice was successful in facilitating communication between team members and supported collaboration when conducting digital design activities. This provided a motivation for educators of the class to better understand the technologies students choose and justification for these choices.

In previous years of the class, 2007-2011, technologies such as video conference, email, wiki pages and forums were used to facilitate communication (Mamo et al., 2015). This observed change towards using social network sites and other social software such as (instant) messengers from 2011-2019, enabled devices like smartphones to be used by students as a primary computing and communication device. This also led to a change in student behaviours from formalised video conference meetings to quick and short communications between students wherever and whenever there was time to reply to a query.

The observations made around the GDP were not unique to this class. Student's behavioural changes in the use of technology had been documented in the literature from 2012 (Hurn, 2012; Gopsill et al., 2015; Mamo et al., 2015; Pektaş, 2015; Klimova, 2016; Brisco et al., 2018).

Why do engineering design students need education on collaboration technology?

There is criticism of learning technology research as highlighted by Beetham and Sharpe (2019), who stated: "Teachers who are excited about these technologies are often accused of using them regardless of whether or not they are pedagogically effective, and even in ignorance of the long tradition of pedagogical evidence thought." If state-of-the-art practices can be identified and implemented within a classroom activity, students will have the experience of building skills in these areas, that are relevant to current practices.

Although there is much published in the literature concerning the benefits and problems of using novel technology, it does not make its way back into the classroom due to a lack of awareness or time constraints of the educators (Brisco et al., 2018).

In addition to participation, students can meaningfully reflect on their interactions with other team members. Reflection is a large part of a good educational experience (Thornton, 2013). And a particular skill to be developed by students in reflective thinking and reflective writing (Grierson, 2010). Within a team, students can discuss and revisit topics that help to develop the design. This is within education and industry based on the link between reflection and design performance (Tang et al., 2012).

Developing students' digital literacy contributes towards readiness when students enter industry, as greater emphasis is placed on teamwork, technology, and globalisation (Andert & Alexakis, 2015) particularly post-pandemic (Stange, 2020). Educators have a responsibility to ensure, where available, that state-of-the-art practices are being imparted to students.

If inadequate technologies are selected, the student team may decide to fill in the gaps by employing more technologies that add additional complexities such as a greater number of communication channels or complex team protocols for managing the sharing of information (Sclater, 2008).

Pedagogical consideration

To develop skills in digital literacy, students must experience digital technologies within a protected environment, as identified by Bohemia & Ghassan, (2012), who stated: "We propose that the proliferation of Web 2.0 technologies and their incorporation into the learning and teaching environment means that academic staff and students will need to develop skills in digital literacy to participate effectively in distributed project-based collaborative work". These skills can be developed in an educational context to benefit future workers as identified by Gopsill, (2014), "If the benefits of technology skill-building could be better understood and communicated to students the next generation of workers will be in a better position to adapt to a modern, agile and dynamic workplace."

Emami, (2009) highlighted a trend in engineering education towards the constructionist learning model. The constructionist model assumes knowledge is created in the mind of the learner based on outside stimuli. For example, within a team discussion, one idea might stimulate the idea of another person based on the interpretation of the idea. The constructionist model is representative of Project-based learning and is supported by reflection activities after learning has taken place (Yang, 2010). The behavioural model supports a traditional lecture style suggesting that knowledge is passed on, for example, from a person to a person, a book to a person, a video to a person etc. (Emami, 2009). Both models reflect well-held world views.

In recent years, pedagogical assumptions in engineering education have focused on the student experience with a focus on how students learn in comparison to what they learn. The strategies active learning promote are useful during team activities to encourage self-learning within a team environment. Engineering work tends to be multidisciplinary and then requires the skills to engage in these types of projects that an educational environment can prepare (Ledwith, 2017). When students are within a team environment they rely on self-learning in research of the topic, and this means students take a share of the responsibility to learn (Kinzie & Kuh, 2004) and can increase knowledge, motivation, and commitment (Núñez-Andrés et al., 2022).

Considering the lessons of global design and the need to instruct students about the requirements of technology use in design and the importance of technology selection, a combination of the theories of learning is required (Ertmer & Newby, 1993). Constructive learning unlocks the fundamentals of theory that students can later experience and reflect upon. And as proposed by Bohemia & Ghassan, (2012) a combination of theories enables the development of skills and digital literacy, that cannot be assumed for all students.

Building an educational experience to Supporting Technology Selection

To support successful technology selection, students and educators must understand technology functionality available and how this functionality satisfies the requirements of the collaborative project work.

The change in the technology used to communicate and conduct collaborative activities, and the change towards novel technologies appeared to support teamwork. Certain teams reported fewer inter-team issues when using technologies (Brisco et al., 2016) and by delivering guidance on technology selection based on what was known at the time within the literature, and experiences from previous iterations of the class, team collaboration issues were reduced (Brisco et al., 2017).

In the following sections, the outcomes of five workshops are reported. The purpose of the workshops was to identify the gaps in knowledge of engineering design students working in collaborative teams. The intended outcomes of the identification of the gaps were to understand how to support students in future years to fill these gaps in knowledge. To fill these gaps, literature was used on the requirements of collaboration in engineering design teams.

Research Methodology

The motivation of this research was to support the identification of suitable technology for collaborative engineering design teams and to develop an educational experience with the purpose of filling the gaps in knowledge of the challenges in technology use by collaborative engineering design teams, and of technology selection practice.

To achieve this motivation the research must identify:

RQ1. What are the challenges in design practice for teams that technology influences?

This research question is initially answered by a systematic literature review to identify the factors that influence successful Computer-Supported Collaborative Design (CSCD) (Brisco et al., 2020). These factors were systematically mapped and categorised to create 19 CSCD requirement statements that formed the basis of the initial workshop lesson. Students will contribute to answering this question by contributing their own knowledge of the challenges they face in collaborative engineering design teams.

RQ2. What are the gaps in knowledge students have, that can be filled by the literature?

This question is answered by conducting workshops with students to identify the challenges faced in collaborative engineering design teams and how to overcome these challenges. If new challenges and solutions are identified, they will make their way into future workshop lessons.

RQ3. Can these gaps in knowledge be filled with a designed educational intervention?

Students taking part in workshops will have the benefit of the knowledge of the literature and of the solutions to gaps in knowledge identified at previous workshops. To answer this question, a design experience was created based on the format and success of the workshops. To ensure students could engage with the class wherever they happen to be in the world, whichever time zone and with restrictions of COVID-19 meaning students would work from home and in their own time, an online course in CSCD was designed to educate on the challenges faced by engineering design teams and how to overcome these challenges, and how to systematically choose technologies based on an understanding of the requirements of collaborative engineering design.

Developing the workshop in CSCD

A systematic literature review was conducted to identify the factors that influence successful CSCD for the design of the workshop in CSCD. The purpose of identifying the factors in the literature was to build knowledge on what was already known about the challenges of technology use in engineering design teams, to educate students on the challenges and how to overcome them. A lecture was created that details the challenges faced.

To support understanding and reflection on the factors that influence successful CSCD, an activity was implemented into the workshop. Students feedback on the outcomes of each part of the workshop to the larger group justifying their decisions. The activity was designed in three parts to support students' educational development.

1. Students are asked in teams to discuss the challenges they face in collaborative engineering design teams.

2. Students are asked to choose three challenges (due to time restrictions) and discuss the functionalities of technology that would help them to overcome the challenges.
3. Students are asked to make recommendations to future engineering design teams on how they can overcome the challenges using technology.

The design of the workshop follows blooms revised taxonomy (Anderson et al., 2001), where students remember experiences from past group projects, understand the experiences through discussion, apply in the context of conceptualising technology functionality (new context), analyse in the context of identifying suitable technology, evaluate by justifying their decisions to the larger group and create new recommendations that can be applied within their own groups or future groups.

Over the years (2016-2018) in which the workshops were conducted, the workshop activities did not change, however, the content of the introduction and conclusion presentations were updated iteratively based on the outcomes of the previous workshops, new literature being published on the topic or questions students had following the workshops. To conclude the workshops section of the research, students who took part in workshop five were asked to identify best practices in conducting collaborative projects.

Table 1 – summary of the workshops over time

Workshop	Class	University	Year	Participants
1	Global Design Project	Strathclyde	2016	26
2	Global Studio	Loughborough	2016	26
3	Global Design Project	Strathclyde	2017	18
4	Global Studio	Loughborough	2017	28
5	Global Design Project	Strathclyde	2018	27

The University ethics procedure was followed with consideration that students as part of the workshops were not advantaged by the learning of the workshop against others within the same class year. The opportunity to take part in the workshops was available to all students.

The first, third and fifth workshop involved students of the Global Design Project class at the department of Design, Manufacturing and Engineering Management, University of Strathclyde with 26, 18 and 27 students respectively, and the second and forth workshops include students of the Global Studio class at Loughborough University School of Design and Creative Arts with 26 and 28 students respectively. 125 students participated in the workshops over the years. A summary is included in Table 1.

Teams of students were formed of between four and eight participants. Students were invited to form their own teams usually with the teams they had been assigned within their projects class. Students of the Global Design Project were Master level final year students from multidisciplinary and multicultural backgrounds. Students of the Global Studio were Bachelor's level final year students. Both projects were based in product design, the degrees attract a high percentage of female students where the class average is around 50% male to female students. The average age of students was 21 years and two months across all workshops.

Teams were supplied with paper, marker pens, and sticky-notes to complete the workshop activities. Teams could record and display the knowledge in whichever way they felt was most appropriate, e.g., lists, mind maps, and sticky-note ideation. Individual outcomes of the workshops are collated for download at: doi.org/10.15129/9647d268-c35a-4c6e-a325-caabbf64c42e

Results and development over time of the workshop

Within this chapter the gaps in knowledge identified by students are defined with the aim to display the development of the workshops towards the creation of an online course in CSCD. Figure 1 displays the development of the workshops with the gaps in knowledge identified. The gaps and development are discussed in the discussion chapter.

To support students understanding of gaps in knowledge identified in workshops 1, additional information was added to confirm that different students will have different expectations of the projects and will also have different contributions due to the requirements of the outcomes of the project at different institutions i.e., the project is a core module at the Scottish University and elective at the Malta University. Helping students to understand that the desired purpose of the product is different for all stakeholders, and that this reflects projects in real-world scenarios was welcome.

This is related to levels of competence of the students who come from different disciplines with different skills and capabilities. Including information on the importance of confirming language and methods outcomes such as using ID Cards (Evans & Pei, 2010) supported the alleviation of problems with substandard outcomes or misunderstandings. This also helped to overcome a common understanding of the problem by encouraging confirmation by all team members on their individual understanding of the problem and the design method they would use to investigate or overcome the problem.

Signposting students towards functionality of digital tools for democratic decision making such as polling tools supporting the gap of the importance of encouraging debate and democratic decision making. This is related to the gap of choosing appropriate technology and lead to an investigation of which technologies are best to support students in CSCD (Brisco et al., 2020). However, it was important to include as part of the workshops information about relevant technologies that may be able to support and why these technologies are appropriate. Students were then encouraged to evaluate technologies throughout their own design projects.

Technology introduced barriers to students where there are solutions at industrial levels that have been researched including Product Lifecycle Management (PLM), data management and recall systems from the likes of Oracle, Autodesk, Siemens, and PTC. Students are unaware of these as they are too expensive to implement or take too long to learn and set up within an educational environment. Alternatives to support data management were emerging at the time of workshop one including Slack and Microsoft Teams. Awareness of these by teams would support understanding of capabilities for future projects.

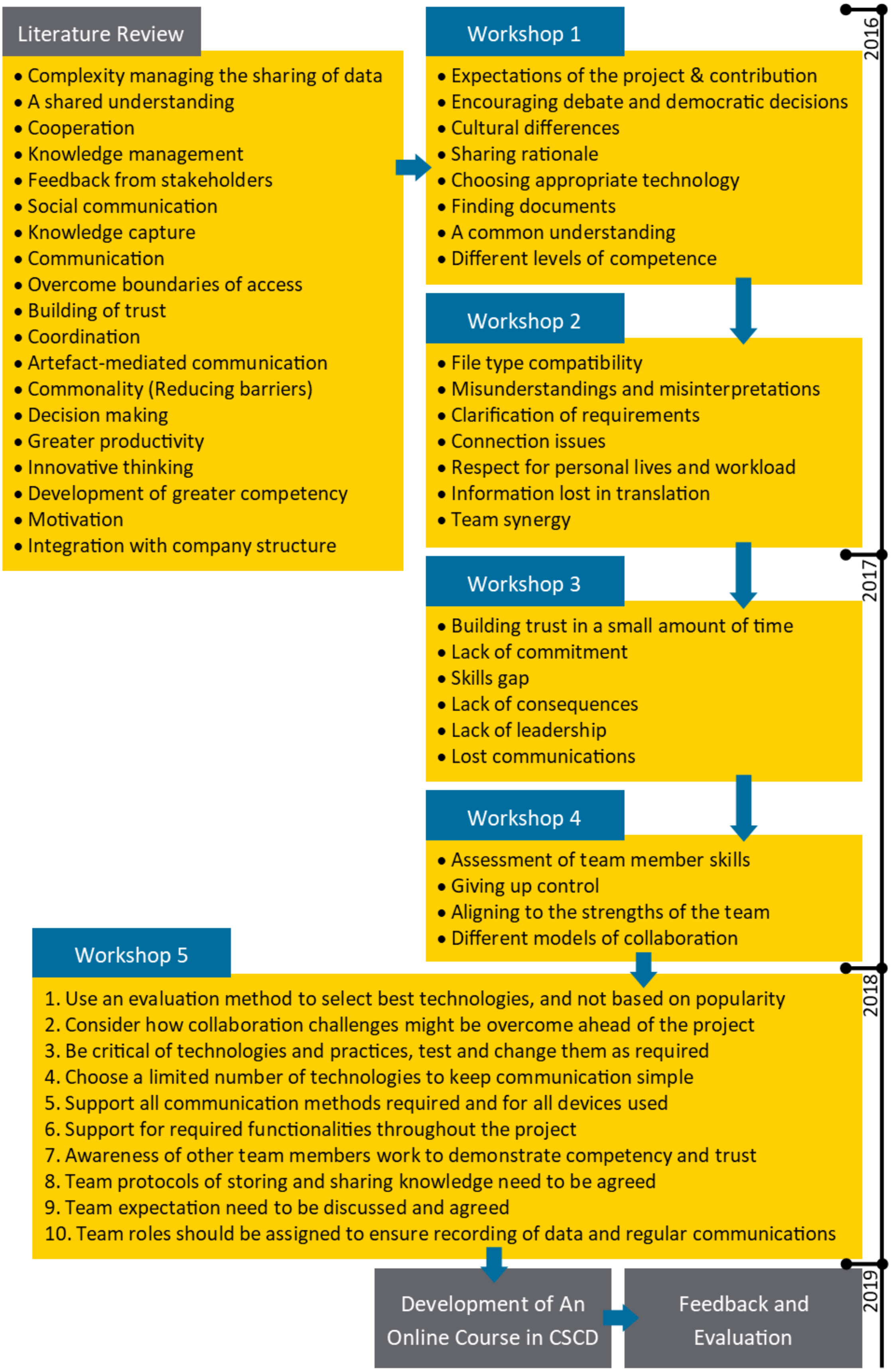

Figure 1 - Graphical representation of the workshop development and gaps in knowledge identification.

Cultural differences were difficult to address due to the nature of the class. Students do not have the time to develop an understanding that cultural differences exist, however they do understand that they have an issue with a particular sub team located in a particular country or with individuals. One example of this is students in the UK believing that the students in Malta are always at the beach, enjoying the sunshine and not focusing on work. This misconception comes from differences in students' cultural misunderstandings about the dedication of students towards their work and is related to the fact that students in Malta are not graded on the outcomes of the class and tend to be of lower year groups where they have more free time in their curriculum. To overcome this gap, students were encouraged to create agreements about working times e.g., 9-5 typical working times, and to create regular meetings to function as motivation for all students.

Due to language barriers, there are issues of sharing rationale. A video was added to the second workshop featuring Starbucks at a Facebook keynote event where the CEO of Starbucks shared his rationale for the use of Facebook for business between shop owners. The sharing of the rationale is crucial to understanding the reasons behind decisions made.

The gaps in knowledge identified by students in workshop two are as follows.

Students in workshop two had novel concerns related to working in groups with students in different time zones, who have different native languages and with major cultural differences. Often information was misunderstood and misinterpreted, requirements were not clarified, and crucial information was lost in translation. Towards Workshop three a technique was added to the lecture to encourage students to double check understanding of instructions i.e., when a student asks another to conduct a task, the other student must repeat back their understanding of what is required. This simple method has the potential to overcome common issues of translation and the same can be completed in text-based communication using a comments system.

As students were more likely to be working with others in faraway countries. Common software and then file types were difficult to manage. A frequent problem experienced in real-world design projects. Students were encouraged to discuss software and evaluate it at the beginning of the project rather than assuming that these barriers could be overcome later.

Due to distance and students relying on home or sometimes mobile internet connections, students did experience connection issues during video and audio calls. Students were encouraged to evaluate software ahead of the projects to determine which software is best for all team members and to try alternative methods i.e., if video is difficult then a phone call may be best, text-based communication could play a larger part in the collaboration, or recorded video/audio messages back and forth.

Once again students were encouraged to define procedures for working such as a standard 9-5 working time during the day and to understand what an acceptable time to respond may be for different communications.

Finally, team synergy was difficult to encourage however encouraging social communication was one way to overcome this that was included as advice in workshop 3. Students may decide to have a social gathering such as eating a meal virtually together. This also supports cultural understanding.

The gaps in knowledge identified by students in workshop three are as follows.

Again, aspects of commitment were raised as a gap in knowledge to overcome. However, another gap did provide a potential solution being lack of consequences. Without consequences for not completing work, other team members would pull up the slack. Again, the answer became encouraging students to make formal agreements at the start of the project of processes and procedures. Beyond this, there was a need to allow students to understand that differences in commitment are common in real-world projects and experience is important in overcoming barriers.

Similarly, the short timeframe of the projects has revealed issues for team members in previous workshops, however during workshop three participants identified that building trust was a key gap in knowledge. To overcome this gap in workshop four, students were encouraged to conduct icebreaker activities and to share more social information. Unfortunately, there is a limit to overcome that may not be possible in such short timeframes of projects. Global design projects such as the EGPR have students collocated for a week to build trust (Kovacevic et al., 2018).

A skills gap was identified for individual students in different disciplines i.e., students involved in design activities who have limited design process knowledge. This became a lesson to educate the students that they will face barriers when those involved in projects come from multidisciplinary backgrounds and rather than dismiss this person's contribution, to find what is unique that they can offer. A mantra of future workshops became 'the right team member for the right task at the right time.' Again, this needs to be discussed openly at the start of the project.

The skills gap is also related to the identified gap of lack of leadership. This was described as a problem with decision making. A top-down company structure would result in the manager having the final decision on the direction, where students in the GDP were encouraged to be democratic. Therefore, decisions made that contradict a student's desire were frustrating to implement. This is a personal developmental lesson for students, and information was added to the workshops on the necessity to give up control during group projects and knowing when to progress for the benefit of the group.

Finally, lost communication was an issue raised at previous workshops in a slightly unique way. The issue of lost communication was having too many communication channels e.g., a message is sent on one platform (Facebook) and responded on another (WhatsApp) that causes confusion and difficulty in the recall of knowledge, rationale, or documents. To overcome this, additional information on technology selection was added to highlight the importance of choosing fully featured technologies and not those that had limited functionality which would then need to be supplemented with the selection of additional technology.

The gaps in knowledge identified by students in workshop four are as follows.

Assessment of team members' skills was difficult to advise on without causing offence to the team member being assessed. However, it is possible to give others a sense of skill through initial activities such as icebreakers. Asking students to collaborate on the design of a sketch, all contributing towards the design with their own drawing and suggesting ideas for improvement acts as both a way of team members introducing themselves and their practice to each other, however also a way of allowing each other to assess sketching abilities. The other area of product development where this could be useful is in assessing CAD skills. CAD skills are a mixture of design work and experience. Products can look very technical (blocky) and not very aesthetically appealing, that other students may think means that the student lack design skills. However, this is a communication error with determining what type of CAD model is desired and selecting the right team member to create this. Often software can also play an influence on the quality of CAD model that is created aesthetically. To support this aspect, further ideas for icebreakers were generated including a CAD brainstorm with initial models generated that must be assembled. This has one difficulty of finding a common CAD package, that has the advantage of allowing students to discuss CAD software packages early in the project and avoiding CAD compatibility issues later in the process.

Another aspect of skills and ability is aligning the project with the skills of the team. The students are asked to develop a product for the class; however, a design methodology or specific tools are not essential for the class. Students can develop the product in whichever way is best. To encourage discussion on the best way to collaborate on the design of the product examples of design projects using technology were added to future workshops including Wikihouse; that uses a wiki tool to collaborate on the design of an open-source house.

This relates to models of collaboration and how teams are structured. To introduce theory from collaboration research into the team's decision making, information on models of collaboration were added to future workshops including the 3C and Minnesota Computer Science Collaboration model.

Finally, a lesson was designed for future workshops at a higher level than those before. Giving up control is an important part of working in a team, both in terms of the direction the project is moving and individual decision making. As students are encouraged to be democratic in their decision making there needs to be an understanding that any one student cannot control every aspect of the product development including the quality of the outcomes. Some of the outcomes will not be exactly as expected, and this is normal for real-world design projects. It is also a lesson to learn that team harmony is more important in certain cases than the quality of outcomes of a small part of the project. This was discussed with students at future workshops.

Following workshop five, the intention was to cease the in-situ workshops and transition to an online learning experience. Towards this need, students were asked to identify best practices in collaborative engineering design working to be used as a guide for students taking part in short form projects.

These best practices became instrumental in the formation of an online course in CSCD to ensure students had a complete understanding of the challenges during collaborative student projects. The iterative design of the workshops ensured that gaps in students' knowledge were considered in the design of the online short course in CSCD.

Development of an online course in CSCD

An online short course in CSCD was envisioned, designed to include the knowledge developed over the course of the five workshops based on students' gaps in knowledge.

At the University of Strathclyde, the learning management system (LMS) is named Myplace and is a highly customised version of Moodle. A first draft of the class was created using Myplace, and although it would be possible to add external students from other universities to the platform, this would be a high administrative task for the staff of the class to manage. There was a need to find a common educational platform or LMS where students could engage in the content. An external LMS enabled full control by the course administrator and the ability to quickly scale to include other global design courses or augmented courses for other contexts.

LMS such as Edmodo, Google Classroom, Moodle, and Blackboard were assessed to find out if they had the required features and functionality. Moodle and Blackboard require personal hosting and a major investment in set-up. Edmodo and Google Classroom was not able to offer the ability to self-enrol in a class and to create lessons in which the user could engage in their own time. After further searching, NEO LMS (neolms.com) was found and offered a simple set-up and self-enrolling features required. A class could be created for the Global Design Projects class and a link could be shared to self-enrol reducing excessive administration.

NEO LMS was selected as the designed LMS for practical reasons. The features of NEO LMS that made it suitable for the class were:

- The ability to have a self-contained class with multiple lessons.
- Self-passed lessons in which students could engage in their own time.
- Functionality to support wiki style forums for class discussions.
- Multimedia functions for video integration.
- Surveys and quizzes to poll student opinions and test recall.

To ensure a comprehensive learning experience, Salmon (2013) five-stage model was employed to ensure that the online course was to appropriate standards. These are:

1. Students were welcomed and encouraged through introductory videos.
2. Small online introductory tasks helped to familiarise students with technology.
3. A demonstration of the course content explained how to engage and find information.
4. Lectures included in the course had knowledge-building activities.
5. Discussion and response were facilitated.

The short online course would consist of three lessons delivered over one week. This was to encourage reflection between lessons and the time for students to engage in additional activities such as discussion forums, used to build trust between students.

Students were recommended to engage in the first lesson on a Monday, the second lesson on a Wednesday and the third and final lesson on a Friday. Each lesson takes approximately 20 minutes to complete making the course 1 hour in total. Students work in their own time and can spend more time completing activities and reflecting if they wish.

Three lessons were developed and were formatted as follows:

1. An Introduction to CSCD

In the first lesson, students are encouraged to discover different technologies that may support their engagement in global collaboration.

- Introduction to the features and functionality of NEO LMS through self-exploration (Introduce yourself activity).
- Introduction to CSCD, typical CSCD technologies, their use and importance for education and industry applications.
- Posing questions about the use of CSCD in global design.
- Question “What are the challenges you may face during the project?”
- Link to ID cards for good communication (Evans et al. 2013).

2. Collaboration Models

In the second lesson, students are introduced to models of collaboration and are asked to reflect on successful collaboration endeavours.

- Models of Collaboration.
- What is Collaboration vs Co-operation, Communication, and Coordination?
- Examples of CSCD projects.
- Question “Which collaboration model might you use during a Global Design Projects and why?”

3. The CSCD matrix

In the final lesson, students are introduced to a matrix that supports technology selection for global collaboration projects.

- Introduction to the requirements of CSCD.
- Introduction to the functionalities of technologies that support CSCD.
- Introduction to the CSCD matrix tool for technology selection.
- Best practices for global design.
- Feedback on the course.

Screenshots from the course are included in Figure 2 – 5.

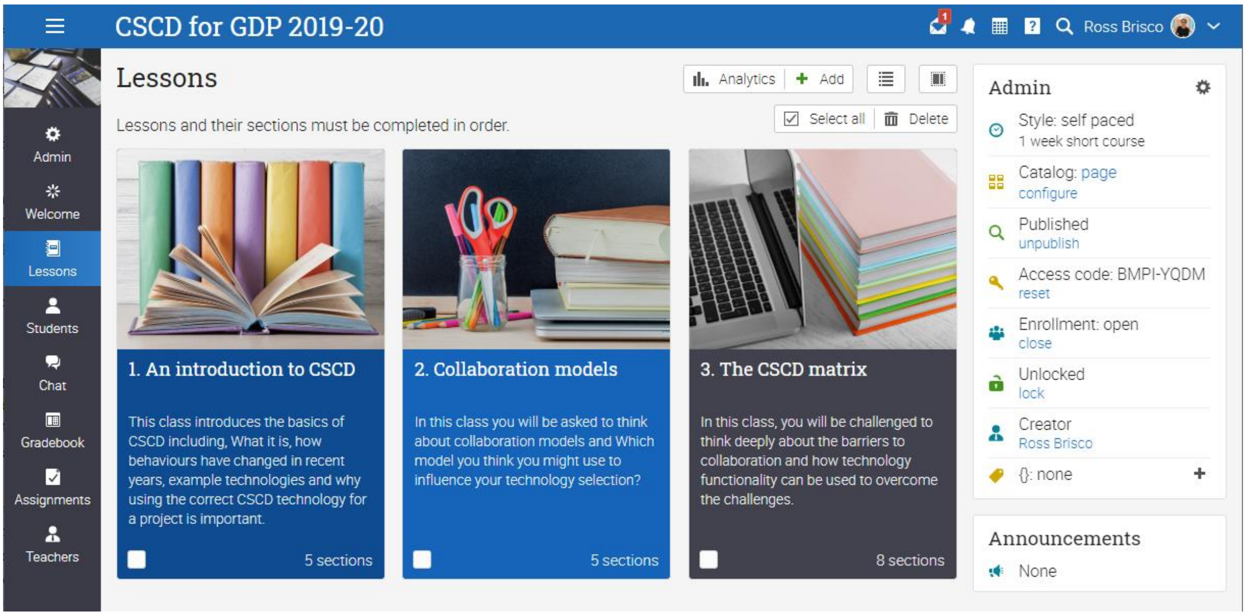

Figure 2 - The welcome page on NEO LMS and connections to the three lessons

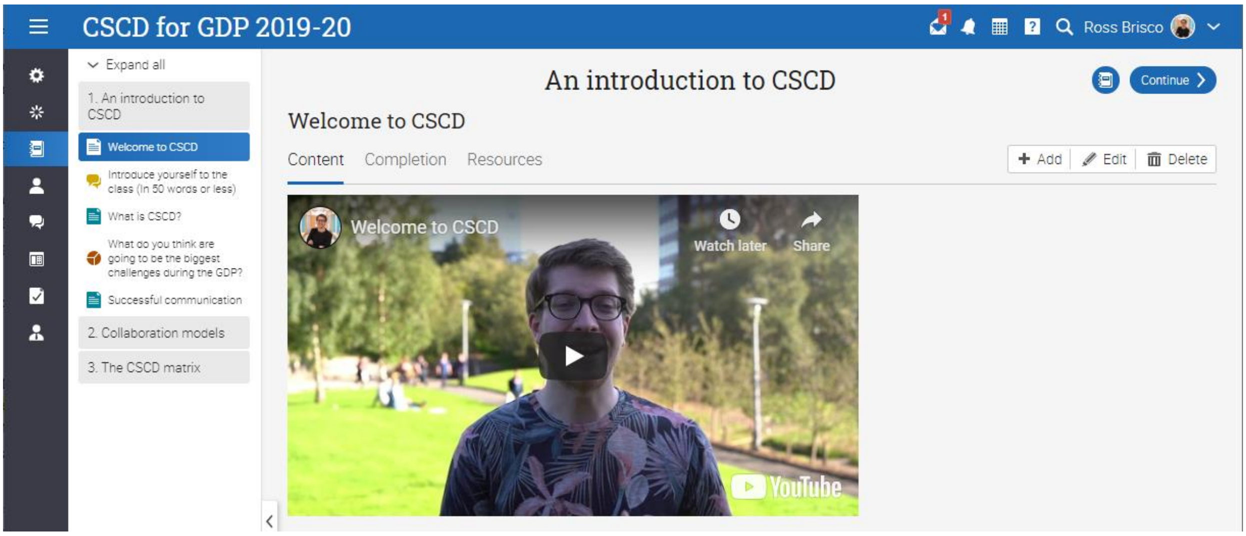

Figure 3 - The first video introduction for the first lesson

To support reflection, students are encouraged to revisit the previous lessons to recap and read comments from other students included in discussion forums. They are also asked to comment on any discussion posts that they find interesting. A mixture of video and text was used based on the content of the lesson. A test was used when simple diagrams might need study and focus, whereas video was used to build a sense of presence and connection with the students.

Text lessons were useful to convey additional information such as websites, connections to publications, connections to external videos or animations of processes. To assess knowledge and encourage reflection, students were challenged to think of answers to questions such as "Which functionalities of technologies were important to overcome challenges in global collaboration?" Students created their comments and then engaged in other answers by reading and responding.

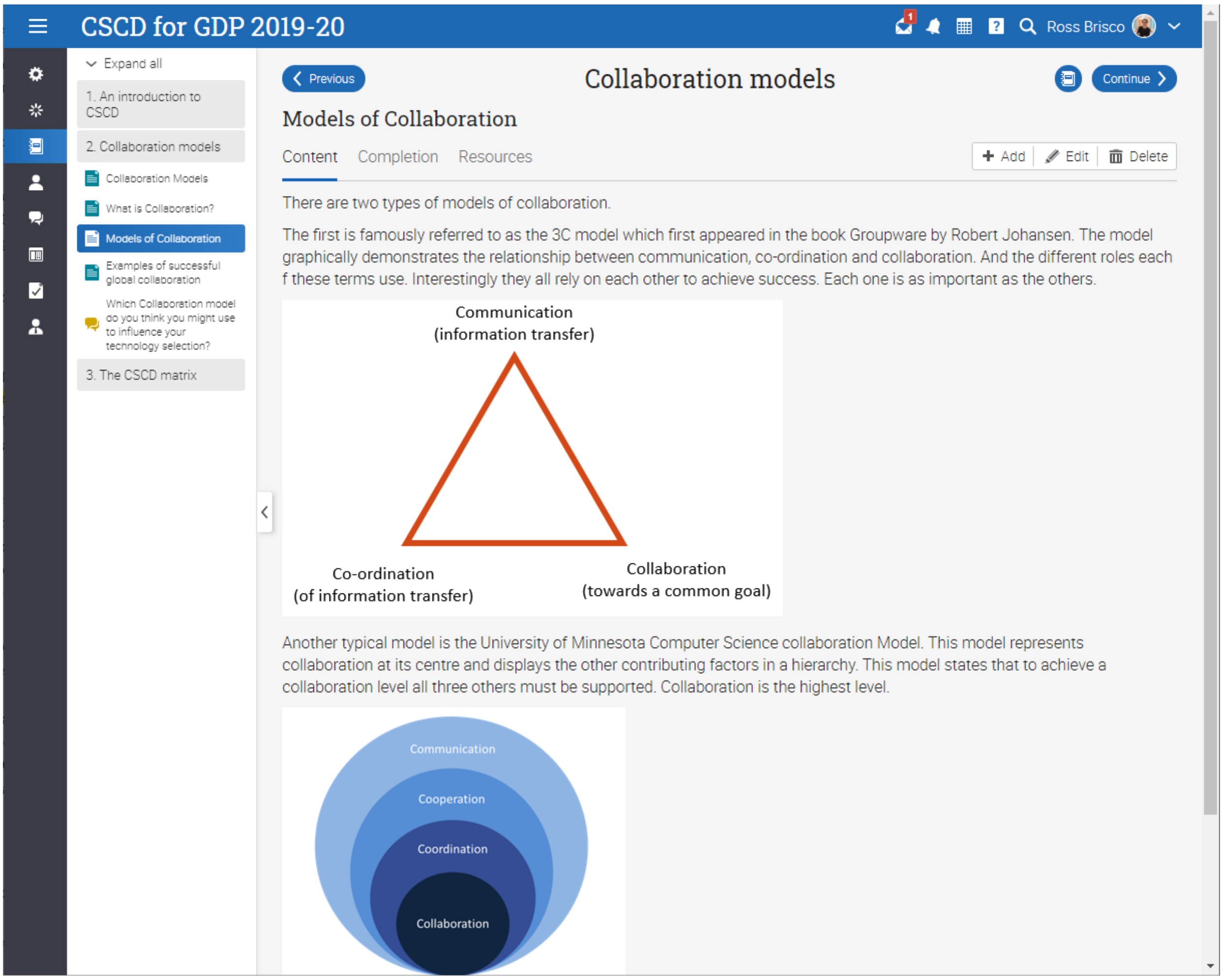

Figure 4 – Lesson on Collaboration models

Figure 5 - An example of a discussion forum to support reflection

Feedback on the online course in CSCD

Students of the first online course in CSCD were asked to provide feedback on their experience with the online course. Three questions were asked, and 38 participants responded.

The first question asked, ‘How prepared do you feel for the Global Design Project following the online short course in CSCD?’ The results (Figure 6) were positive with most students agreeing that they were highly prepared (14 of the 38 students) or somewhat prepared (20 of the 38 students). Three of the students felt somewhat unprepared.

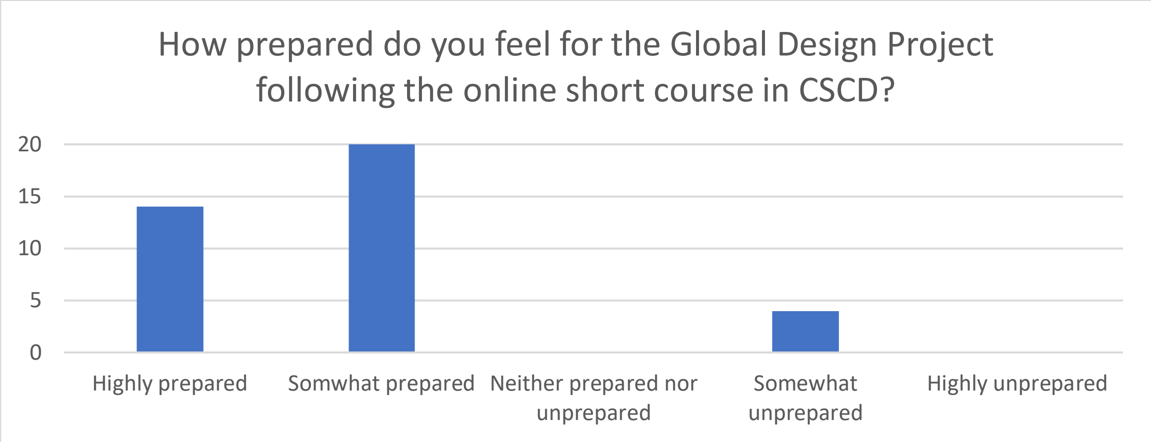

Figure 6 - Response to the survey question on how prepared students feel for their collaborative projects following the course.

The second question asked, ‘How prepared are you to select technology based on the knowledge gained from the online short course in CSCD?’ The results (Figure 7) were again positive with most students agreeing that they were highly prepared (19 of the 38 students) or somewhat prepared (16 of the 38 students). Three of the students felt somewhat unprepared.

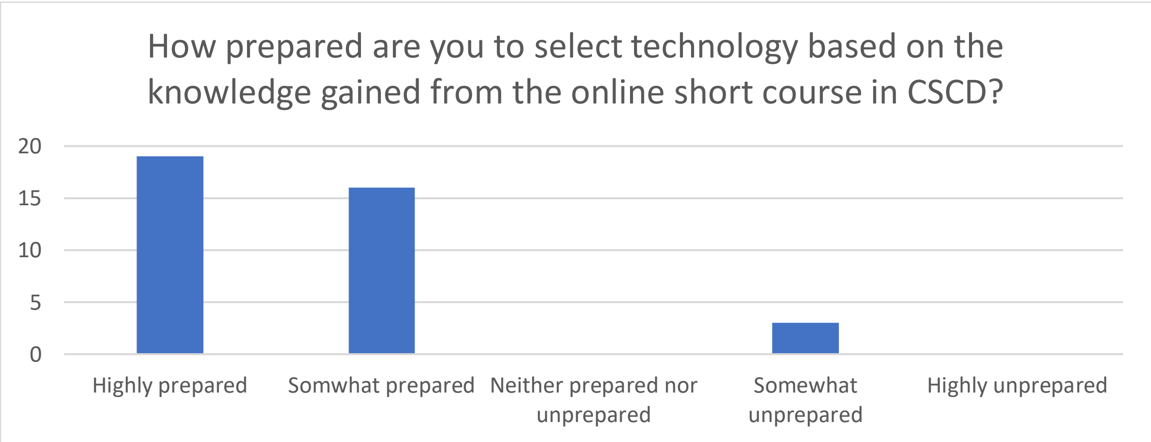

Figure 7 - Response to the survey question on how prepared students feel in selecting technology following the course.

An open response question was included in the questionnaire for any other feedback (Figure 8). This feedback was coded to understand future developmental needs of the class. Two students agreed that “More examples and case studies” would be useful and that “Terminology was difficult to understand" which highlights a trend if negligible based on the numbers. Other students commented they were "Confused by one or more parts of the course," "Difficult to contextualise knowledge," "Difficult to justify my own opinions," "Knowledge was contradictory with student experience" and "Overly complex for the lessons."

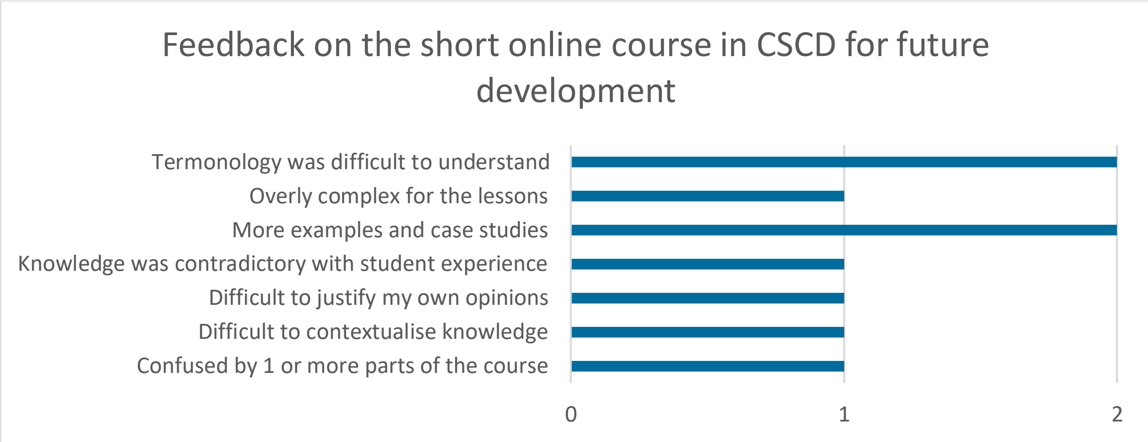

Figure 8 – Feedback received on the short course

Addition of the CSCD matrix to support technology selection

A major gap in knowledge identified during the development of the workshops was students having justification for the identification of technologies suitable for their projects. Students chose software they were familiar with rather than justifying their technology choice based on the merits of the technology and availability to all team members. If students had guidance on the requirements of technology for their projects, and a systematic way to choose the technology based on the requirements, then the learning associated with technology choice would be beneficial for their educational development rather than happenstance.

A solution was identified in the CSCD matrix (Brisco et al., 2020). That enables a systematic evaluation of individual technology or technology packages to determine if they have the functionality to support collaborative requirements. Students are guided to identify technologies, identify the functionalities of the technologies, and then link the functionalities with the requirements of CSCD that are already determined and categorised (from a literature review and thematic coding).

The CSCD matrix was first included in the 2018 workshop, with the majority of students in a follow-up questionnaire (Figure 9) agreeing that the matrix was highly relevant (18 out of 28 students) and the reminder that the matrix is somewhat relevant (10 out of 28 students). The other options were neither relevant or irrelevant, somewhat irrelevant, or highly irrelevant. All student's responded that the workshop contributed positively towards their understanding of CSCD.

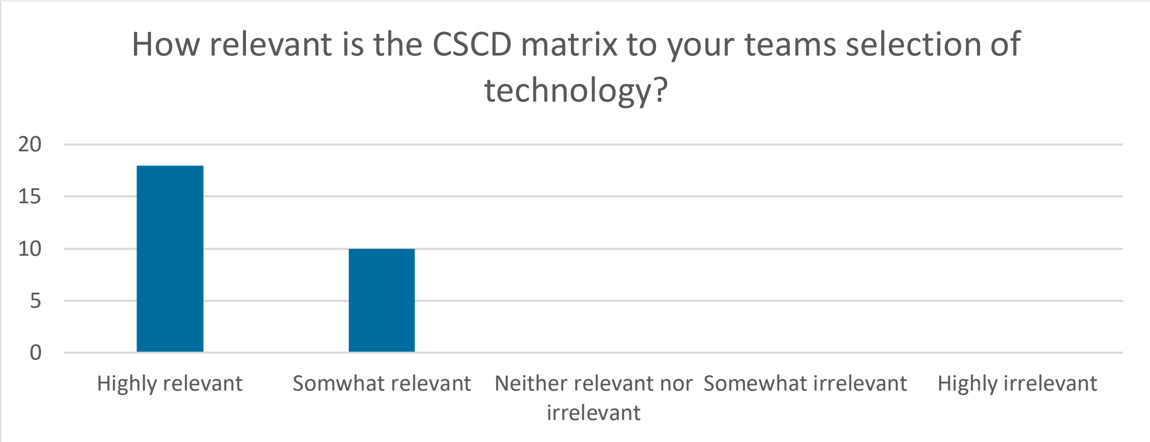

Figure 9 - Response to the survey question on the relevance of the CSCD matrix to students' education

The results for the student's understanding of the CSCD matrix (Figure 10) was highly mixed with the majority of students agreeing with a little help they could use the CSCD matrix (15 out of 28 students) and slightly fewer agreeing that with a lot of help they could use the CSCD matrix (8 out of 28 students). Although the majority felt they could use the CSCD matrix with little or no guidance, a considerable proportion would struggle to use it for their projects.

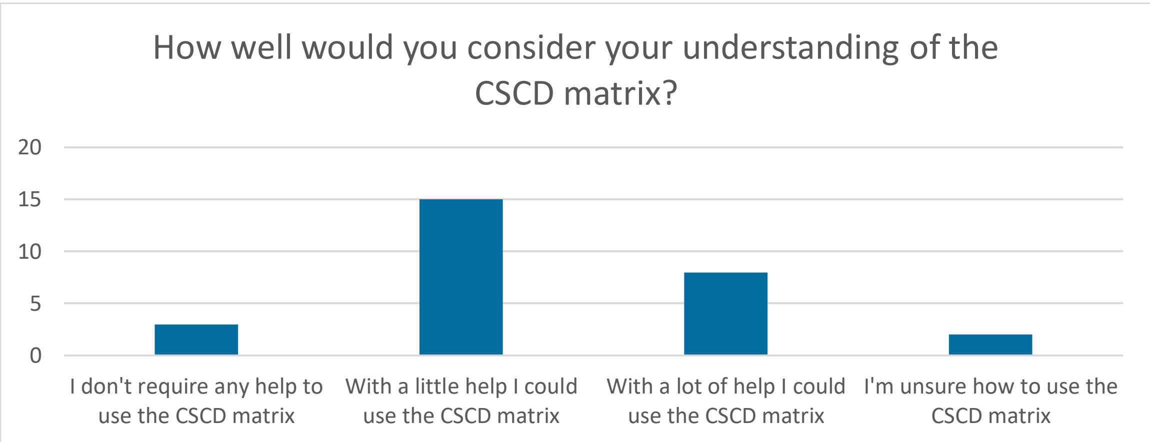

Figure 10 - Response to the survey question on how well the matrix is understood by students

Students shared reasons for the lack of understanding that were needed for further clarity including "matrix works but is somewhat hard to understand," particularly in the method of the CSCD matrix creation, "The purpose of the numbers on the sides of the matrix and how they are derived is unclear." Upon reflection, It was difficult for students to move from understanding collaboration requirements to applying them within the matrix.

Following the students' projects in 2018 a further survey was distributed, asking how students used the CSCD matrix. The following responses were the ways that the matrix was used "To evaluate technologies at the start of the project", "To identify the most appropriate technologies", "To overcome barriers when challenges arose due to technology use", "To ensure that the correct tools are used throughout the project" and "As a supportive tool to help the team discuss the available technologies."

There were several benefits observed in the workshops. The outcomes of discussions with the students identified problems that might impact CSCD education. Project-based learning is a well-established method of teaching, especially in building soft skills, and there appears to be a gap in the publication of reflections on the classroom to be shared and implemented in future classes. This type of collaboration would improve knowledge of the requirements of CSCD for all students to benefit. The approach of these workshops is to give students state-of-the-art information by reflecting on issues of the previous GDP year and other related classes. Students can then decide to engage and implement practices as they determine appropriate, and they are at least aware and prepared.

As students use the CSCD matrix to discuss implications for their projects, a student can apply their knowledge of technologies they are familiar with, functionalities they are familiar with and knowledge of the CSCD requirements. Students function as both the learner and the expert. This empowers the students to take responsibility for their learning experience to implement informed decision and creating protocols of working.

One unintended outcome was the student's reflection on their own performance towards the team's goals. Students of the GDP struggle to make comments on their own behaviours, however, the CSCD matrix is establishing a baseline in terms of the requirements of technology, and the student have been able to understand the human aspect in technology use. Critical analysis of oneself is essential for reflection and improvement for future projects.

With the benefits of the CSCD matrix established for inclusion within the online short course in CSCD, an investigation was established into the best way to present the matrix at an appropriate level of abstraction for final year students' education.

Feedback from the workshop in 2018 on difficulties understanding how to use the CSCD matrix was addressed by simplifying the activity. Rather than displaying the matrix with the full set of requirements for collaboration (19 in total), students were first given a CSCD matrix example with one requirement, one technology and five functionalities. Once they felt confident, students could progress to more complex versions of the matrix e.g., three technologies, six functionalities and six requirements. The rationale for this was to link with Mamo et al. (2015), who identifies the requirements of four technologies within student's collaborative design projects.

Students were introduced to the CSCD matrix (Figure 11) within the final lesson of the online short course that allows students to learn about collaborative requirements and reflect on the requirements before moving on to applying the knowledge within the CSCD matrix activity.

Students would have the ability to revisit earlier weeks if they struggled to consider the requirements. Once familiar with this simplified matrix, the students can move on to the full matrix, that could be used to complete their technology investigations towards technology selection as a team.

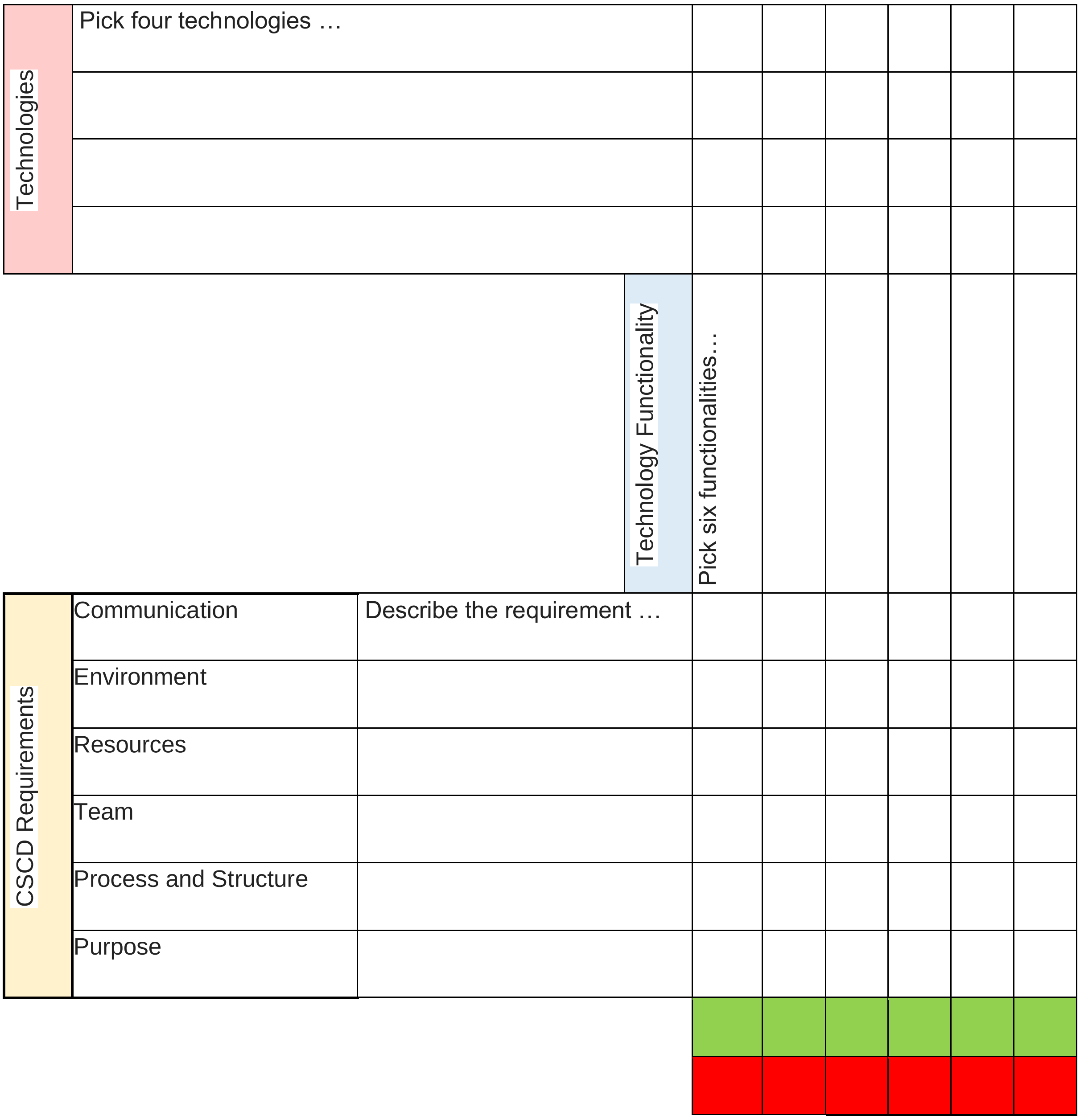

Figure 11 – Simplified CSCD matrix for use by students during the online short course in CSCD

Feedback from the online course was used to evaluate how successful the CSCD matrix education was in the online format (Figure 12) and split into smaller lessons that build to the full matrix. 38 students responded to the feedback request. Half of the students agree that they did not require any help with using the matrix (19 out of 38 students) and their understanding was high. A minority said that with a little help they could use the CSCD matrix (16 out of 38 students) and slightly fewer agreeing that with a lot of help they could use the CSCD matrix (3 out of 38 students). This was a significant improvement on the workshops before.

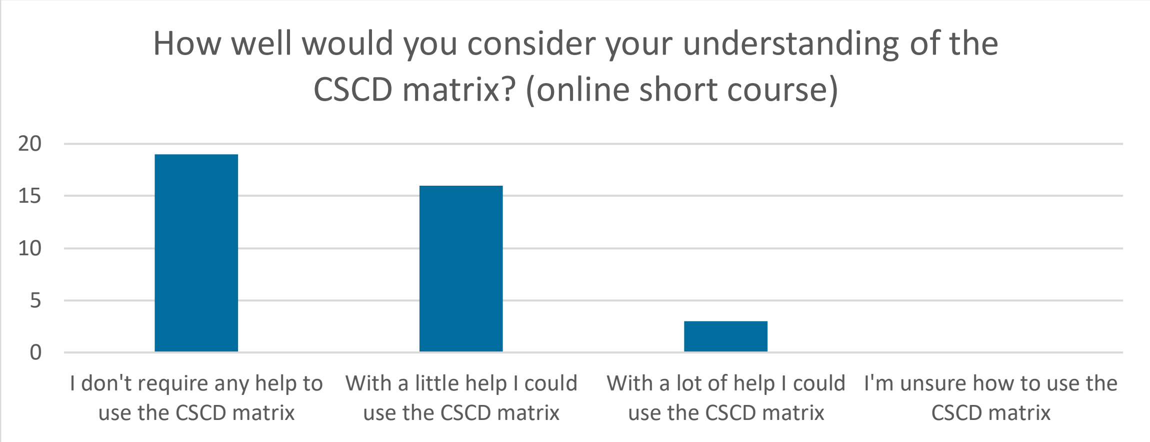

Figure 12 – Response to the survey question on the understanding of the matrix by students

Following the specific answers on the CSCD matrix, there were some general comments asking for more examples of projects in future versions of the course and to simplify the content further. Most students, 90% stated that the class has prepared them fully for the collaborative design projects with 10% stating they were somewhat prepared.

Discussion

In this section, the outcomes of supporting technology selection in collaborative engineering design student teams are discussed. First, there are insights following the identification of gaps in students' knowledge as part of the iterative development of the workshops. Secondly, the development of the online short course in CSCD led to insights for other educators developing similar courses both for discipline and also format. And finally, a discussion on the use of the CSCD matrix within an educational environment and an evaluation of its use within an educational context. Throughout the discussion section implications for policy, research, educational practice, or policy are discussed.

Gaps in students' knowledge

A motivation of the online course development was to fill gaps in students' knowledge about CSCD. By filling these gaps, students would be in a better position to conduct distributed collaborative design projects. Gaps in students' knowledge were identified through a literature review of collaborative engineering design and an educational workshop.

Almost all the gaps identified were not unique to CSCD and could be barriers in research on Computer Supported Collaborative Work (CSCW). However, there are key gaps in the context of design that make them unique to design.

Sharing rationale is difficult in a digital visual context as the tool used must allow for annotations to figures to share rationale and contextualise the drawings. This is used to highlight that what may be appropriate for one educational environment may not be appropriate for another.

Similarly, Different models of collaboration may be appropriate in a design project context that may not be appropriate in other educational domains. However, the topic is appropriate to consider as identifying appropriate models of collaboration is important to consider for all domains that are subject specific.

Emerging issues caused by technology use in design projects may highlight the current and future challenges of this generation of students and the next. Respect for others personal lives and workload was a key gap that highlights changing behaviours towards education where if one student feels they are available 24/7 then others could or should be also.

A key lesson from identifying gaps in knowledge and reflecting on teamwork practice is understanding that what is experienced within an educational environment is indicative of real-world practice. Reassurance that the same situations will arise when students move into industry jobs and having experience of how to overcome challenges is a lesson.

Case studies were used during all workshops, however, more examples and case studies were requested. Although learning of the requirements of collaboration was competent throughout, there is a gap in the student's ability to contextualise the knowledge within their own projects in which case studies can support their learning.

As workshops progressed and gaps were filled, the gaps identified in the later workshops were fundamentally different to those in the earlier workshops. Students identified practical gaps in knowledge early on including choosing appropriate technology, finding documents, file type compatibility and connection issues. However, these gaps were discussed in later workshops and ways of overcoming these gaps were suggested to students meaning the gaps had been filled. Gaps that remained included giving up control, aligning to the strengths of the team and skills gap that are more complex in nature to solve depending on aspects related to the individual team members and the requirements of the project. There is a depth in the gaps identified in the later workshops that require a deeper discussion about the challenges associated before solutions can be reached.

Gaps were communicated from one workshop to the next with the redesign of the introduction and concluding presentation slides. For example, Workshop 1 outcomes led to the inclusion of new material in workshop 2 in the introduction slides, specifically a slide and discussion on cultural differences in design teams and the benefits for global design. This was the same for workshops 3 and 4. The outcomes of workshop 4 were presented to workshop 5 in the form of virtual sticky-notes that were discussed with students.

Students were told that the previous studies took place after the workshop was complete. They were also introduced to the outcomes of the workshops as 'recommendations for future students' in concluding slides. This functioned as short interventions the teams could quickly act on within their teams.

Reflections on the development of an online short course in CSCD

The success of the method of development of the online short course in CSCD is prevalent in the response from students to the survey questions. It is important to preface any results around this time as being pre COVID-19 pandemic (September to December 2019) and to reflect that the students did not have exposure to online learning courses. All other aspects of the class where studio-based learning as a signature pedagogy in engineering design education is, however, the nature of global design is digital, and students' collaboration was almost always conducted online.

The process of iterative development has ensured an appropriate learning experience for students with the appropriate knowledge to complement their gaps in knowledge. This process is not dissimilar to the customary practice of iterative development of a module year on year based on student feedback. What is unique, is the focus on filling gaps in student knowledge based on the literature rather than an approach to satisfy student experience and introduce the latest knowledge into the classroom. Taking this approach has delivered a complete learning experience required by students for their global design projects.

It is expected that the approach will be interesting to others who are developing or who conduct regular global design classes and others who teach in the areas of distributed design or who are working to develop flipped classroom experience for students.

Students shared text feedback on aspects of the class which they thought worked well and other that they felt required further development. One student wrote "I found part 2 about the collaboration methods to be a bit confusing. The two models presented were not explained with enough detail … I did not find that the graphical representations explained the concepts very well and (I) was not able to find much information through the internet on each model." Reflecting on this student experience there are obvious nuances between lecture based and online learning. The online short course was designed to be completely asynchronous and self-led, so there was no opportunities for students to ask questions or clarify the learning experience. It is necessary even within these restrictions to have opportunities for questions and answers in the form of a forum or comments section. This required the teacher to have an active role in conducting the class that was not the intention due to the asynchronous nature of how students interact with the content. Alternatively, the lesson on collaborative models does not suit a digital environment as it is currently designed and requires further development.

Another student shared what could become a growing issue as more diverse students join the class related to terminology, more attention needs to be taken to clarifying the language used that may be completely unfamiliar to non-native English speakers. Words such as Asynchronous and synchronous, or collocated and distributed are not common terms.

A final comment from a student that would lead to improvements was "I was shocked to learn that students prefer video conference to audio conference. To me video is just pain to set up and does not add anything." This reflection highlights the importance of building an understanding of global design projects and managing the expectation of the students who engage in these classes. However, the course is not designed to support students to overcome their preconceived bias, in this case, stemming from cultural differences or personal experience. This has highlighted that the online short course method is not a replacement for monitoring or tutoring to encourage students to share personal reflections with each other and work to find a common ground. This may become a formal exercise as part of the course. Something that the reflective forums could not achieve.

Conclusion

This paper conveys the development of an online course in CSCD. The need for a course to support students' education on collaborative requirements, and technology evaluation and selection was established through observations of the Global Design Class and changes in technology over time from the literature. To support this development, literature on pedagogical considerations of course development was identified to establish a suitable methodology. To ensure the workshops and later online course were fully considerate of the requirements of modern students, three research questions were established: What are the challenges in design practice for collaborative engineering design teams that technology influences?, What are the gaps in knowledge that students have, that can be filled by the literature?, and Can these gaps in knowledge be filled with a designed educational intervention? The methodology chosen was the development of a workshop and iterative development of workshops over time to ensure student's gaps in knowledge on CSCD were filled and fully considered for a robust course.

The workshop was designed with multiple parts, an introductory lecture on CSCD, an activity on the challenges and how to overcome challenges of CSCD and concluding slides to summarise the outcomes. The activity of the workshop was designed to ensure robust student reflection on the challenges of CSCD and to inform the educators of the gaps in students' knowledge. Future workshops would develop with an expanded introductory lecture and discussion based on the previous identified gaps.

The workshops took place over three years with students of two universities and two different global design classes. Teams of students worked together to identify the challenges and how to overcome challenges. In total 125 students took part.

To build the first lecture, literature was used on challenges of collaborative global design or recommendations to inform students of best practices. Moving forward, gaps in knowledge from the workshops from previous workshops were added to the next workshop lecture and discussion around the topic supported understanding. As the workshops progressed the observations of the educators in the class were that the gaps in knowledge were becoming of a higher abstraction level and less practical, and the number of gaps was decreasing, supporting the methodology of the workshop development. Gaps in knowledge such as how to deal with cultural differences and techniques and tools to do so were replaced with personal reflections on a designer's ability to give up control for a design's development as part of a design team when appropriate.

Following the creation of a robust version of this workshop, the knowledge and understanding of student's requirements were transferred to an online short course enabling all students in the global projects to take part. The online context of the course prepares students for group projects by giving them an experience of learning and collaborating online. The knowledge taught during the short online course includes known gaps in students' knowledge based on previous workshops.

The class was developed on NEO LMS for practical reasons and full consideration was given to the experience of learning online compared with in person using pedagogical frameworks, such as (Salmon, 2013). The online short course encourages students to reflect on their answers to key questions about the challenges and overcoming challenges of global collaboration.

The developed online weeklong class is independent of the Global Design Project. Students are encouraged to engage with the content across three separate days to encourage reflection using forums and questions. The online course reflects the success of the workshops with introductory lectures, reflection on challenges of CSCD and how to overcome challenges and recommendations for students to implement. With minor modifications, it can be developed for a more generic audience. This novel class has been prepared for a higher education audience however it can be adapted for different disciplines and education levels.

The method of the course development has proven successful in the creation of a robust learning experience. Students have responded that they feel prepared for the Global projects by taking part in the online course in their ability to select suitable technology that requires a robust knowledge of CSCD. Feedback for improvement was limited and will be considered for future versions of the course.

The CSCD matrix was used to help answer RQ3. As a design intervention to support technology evaluation and selection. Feedback on the CSCD matrix was positive, and with perhaps an indication that there is development required to the online course to fully support comprehension of the method and how to use it. However, students understand that the tool is highly relevant to their education.

The paper summarises the gaps in knowledge of the students along with reflections on the development of the short course moving forward and for others who are considering the development of similar courses. The authors are interested in re-examining the course design and development post-covid to identify any changes that were required in the design of the course to better support students working remotely. The course is available to all who would be interested in implementing it as part of their modules.

Acknowledgements

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