Introduction

We are witnessing a rapid growing complexity in contemporary products and their designs, for example, from electronic, aerospace and automotive industries. Moreover, in a globalized world products are typically designed and manufactured in several locations and in different countries (Frederic Segonds et al., 2011). Engineers and designers face huge challenges as they manage increasing product complexity and diversity so as to satisfy customer demand, while trying to accelerate the design process to deal with the competitive realities of a global market and decreasing product life cycles (Schaefer et al., 2012; Häfner et al., 2013). The development of collaborative virtual environments has allowed all stakeholders from different locations to work together in order to reach an agreement and make shared decisions that decrease time and cost to bring new, high-performance and reliable products to the market (Verhagena et al., 2012).

In order to be competitive in the global market, engineering graduates must have capacity to work within a virtual global environment (Thoben and Schwesig, 2002) and be able to work in multidisciplinary teams (Häfner et al., 2013). As educators, we have an obligation to educate our students and to develop our engineering courses, in line with the real and constantly evolving requirements of the industry (Ye et al., 2004; Spinks et al., 2006; Silvia and Beatriz, 2012). There have been significant changes in design curricula in RMIT University to allow engineering students to perform real-time geometric modifications and concurrent designs provided by collaborative virtual environments, which is regarded as world-best practice. The virtual environment can allow multiple users, whether remote or onsite, to develop and explore virtual 3D models collaboratively (Yabuki, 2011), which are not readily available in physical environments (Kvan et al., 2004; Gu and Merrick, 2011).

RMIT University now has the facility to use a Computer Aided Engineering (CAE) digital platform, which delivers a 3D user experience to allow students to perform collaborative design. Students can connect with peers, access data and generate solutions on a single intuitive digital environment. We aim to create an environment that maximizes the value and quality of students' learning experiences and outcomes by ensuring that these experiences are as close to the real-world activity as possible. It is essential that students develop skills for digital collaboration.

Aim of the paper

This project aimed to evaluate benefits for students using a digital platform (CATIA v6R2013x for Academia) to manage engineering design projects, particularly relating to communication, experience in collaboration, and the development of knowledge and skills. The project addressed how students perform in a virtual, project-based learning (PBL) environment, and delivered recommendations on the development of pedagogy in collaborative design research using a digital environment.

Course design

In the first year of the undergraduate degree, students from the School studying aerospace, mechanical, automotive, mechatronics and manufacturing engineering are enrolled in three core courses that focus on project-based learning (PBL). These courses are MIET2093, AERO2248 and MIET2419, with the first using a virtual environment to manage PBL, whereas the latter two courses using traditional face-to-face PBL.

MIET2093 is a design course during which students are introduced to CAD software, such as CATIA v6R2013x for Academia, during the laboratory sessions. The CAD software provides students the opportunities to use the latest 3D and Product Lifecycle Management (PLM) virtual platform from different sites to collaborate effectively during the design phase. The virtual platform also allows students to perform real-time geometric modifications and concurrent designs of different components/sub-assemblies taking into consideration a wide range of design and engineering requirements. Students were given nine weeks to work on a collaborative design project that involved the utilization of CAD software and the production of prototypes using a 3D printer. Each member has an individual task to produce a single component. The groups' members decide how to distribute the task within the team. Procedures and methods in creating 3D CAD models are explained in weekly CAD computer laboratory sessions. Students are encouraged to explore different design possibilities and share understandings of design goals during the collaborative process.

In the AERO2248 course, students learning activities are largely focused on the Engineers Without Borders (EWB) challenge, which allows students to develop professional skills in a team environment. Team members are required to nominate a design area for the EWB challenge and establish team protocols. During the semester, the assessment of group work includes a series of formal presentations and a final report. In the MIET2419 course, students work in groups to design and build a spaghetti bridge based on the length and weigh specifications that can support a car that weighs 2kg to pass through 10 times without damage. Peer-review is also part of the formal assessments for these two courses.

Table 1: Courses surveyed in the research

Course (Code)	Enrolment Number	Design Project	Design Project assessments
Computer Aided Design (MIET2093)	187	Office and Industrial tools	Report
Engineering, Society, Sustainability (AERO2248)	294	Engineers Without Borders (EWB)	Report, presentations and peer assessment
Mechanical and Materials 1 (MIET2419)	294	Spaghetti bridge design	Report and peer assessment

Student Survey

This project was granted approval by the RMIT University Human Ethics Research Committee. Students enrolled in MIET2093, AERO2248 and MIET2419 were invited to take part in the project during the mid semester and at the end of the semester (in Week 5 and Week 11). The administration of the mid semester survey was designed as a pre-test; the end semester survey was designed as post-test. This paper is not reporting on the comparing the two surveys, but is reporting on students' responses to the second survey. Students were asked a series of questions to investigate their attitudes and learning about digital environments and face-to-face PBL (viz. satisfaction, perceived performance, participation/engagement, feedback, and skills developed). The survey was distributed during the two-hour class and the survey took five to ten minutes to complete, so that the students would not be disturbed in their studies. Most questions required students to select an option from a five-point Likert scale, indicating the level of agreement or frequency related to a corresponding statement. One short open-ended question was included at the end of the survey to allow respondents to offer feedback on their own words.

Students were advised that their participation in the survey was anonymous, and did not form part of the formal assessment in the course. There are no discernible risks associated with their participations in the survey, and it would not impact on their marks or grades in the course. None of the authors was responsible for facilitating the survey; this was handled by a project officer. The authors remained neutral and had no influence on student responses.

Student Profile

Total enrolment in MIET2093, AERO2248, and MIET2419 in semester one, 2015, was 187, 294, and 294, respectively. Of these, 125 were enrolled in both MIET2093, and AERO2248, 139 were enrolled in both MIET2093, MIET2419, and 103 were enrolled all three courses.

A total of 31 students participated in the first round of survey with six females and 25 males, ages ranged from 18 to 30 years. Eighty-four students responded to the second round of survey (17 females and 67 males) with 81% aged from 18 to 20 years. More than 65% of the students had indicated that they had not taken any formal CAD training and had never used any virtual platform to perform collaborative design. The analysis of the results for this paper was focused on the second round of survey.

Results

Students' engagement

Figure 1 shows the frequency of students contributing to group discussion with team members via face-to-face and virtual platform. The results show that students contributed more often (combining "always" and "often") to face-to-face group discussion (90%) compared with the virtual environment (70%). Figure 2 shows results for questions that asked students to indicate how often they worked with team members to complete the design project. The results indicate that students prefer to work with team members in face-to-face approach compared with the virtual environment.

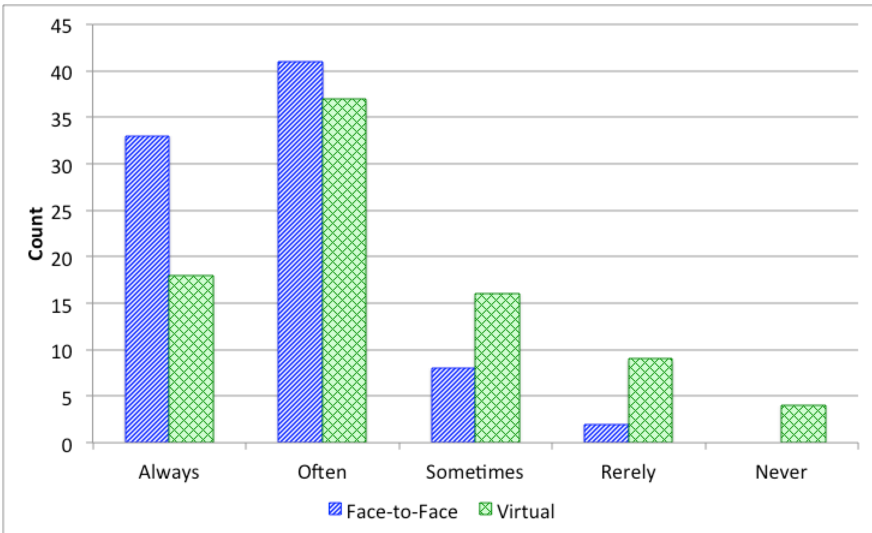


Figure 1: Contribution to group discussion

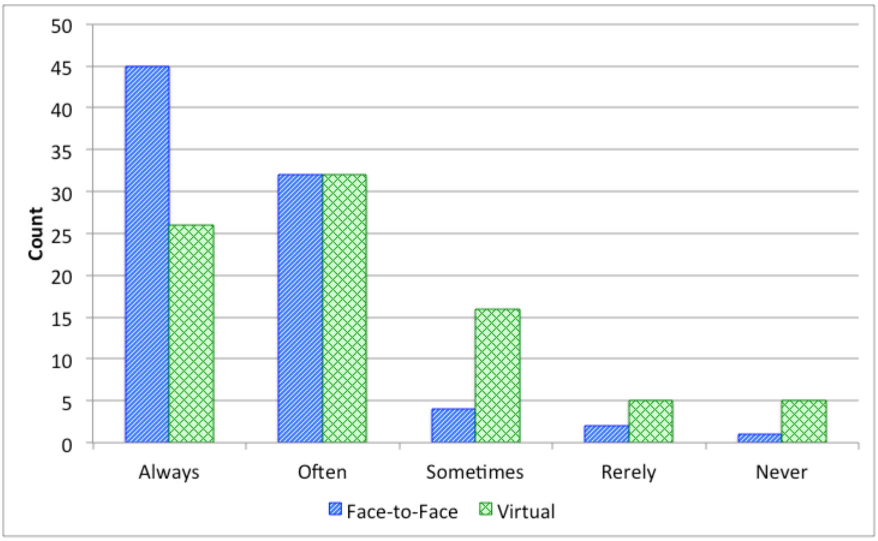


Figure 2: How often students worked with team members to complete the design project

Students' perceptions

Students were also asked to rate their perceptions of collaborative design using a virtual environment in terms of their learning efficiency, communication with peers and professional development. When asked about their perceptions, they were instructed to use the following scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree. Figure 3 shows that students tend to agree (60%, combining "strongly agree" and "agree") that online PBL offers an efficient way of learning because they can access data and generate solutions on a single virtual platform. Thirty precent of students agreed that, in terms of professional development, the online PBL provided them with an environment that maximized their learning outcomes; whereas 50% students were neutral on this question. Only 40% of students agreed that the digital environment allowed them to communicate and collaborate better with their peers; 40% of the responses were neutral. In general, students' perception of collaborative design using virtual environment was positive and they could see the usefulness of the virtual platform.

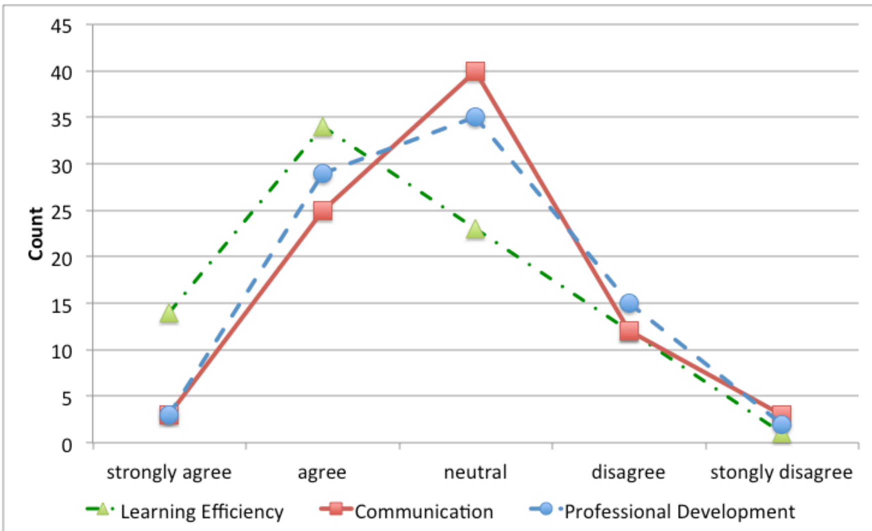
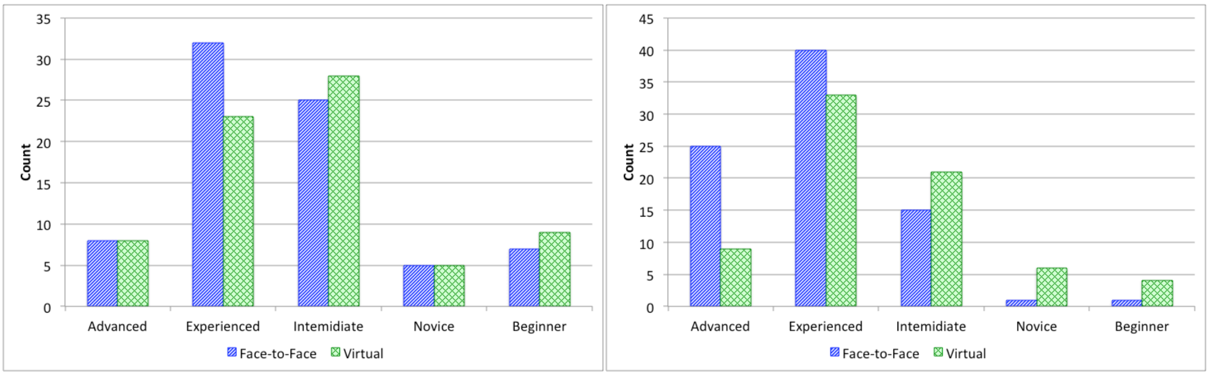


Figure 3: Students' perceptions on collaborative design using a virtual environment

Skills development

Students were asked to reflect on the skill level they developed for the PBL projects in MIET2093, AERO2248, and MIET2419 in semester one or for the past 12 weeks. The results in Figure 4 indicate that students developed higher levels of design skills (combining "advanced" and "experienced") through face-to-face (50%) collaboration compared with virtual collaboration (40%). Similarly, students developed better teamwork skills with their peers during face-to-face interaction (80%).



Design skills | Teamwork skills

Figure 4: Design and teamwork skill development

Open-ended respond

One short, open-ended question was included at the end of the survey to allow students to offer feedback on their own words. One student wrote:

> *Have indeed learnt more from face-to-face PBL than Virtual PBL. Having to be able to convey information physically and having the time and space to that allow immediate transference of information/discussion. Information often misunderstood when down over an online platform/medium especially when not made explicit or urgent.*

This student indicated that face-to-face PBL actually improved the learning outcome. However, team members found the response time delays and misunderstandings often happened due to text communication in the virtual environment and this did not improve the perceived learning outcome. Another student wrote:

> *Face-to-face PBL allows for better communication and sharing of ideas compared to virtual PBL as some members may not be able to use programs such as Catia V6*

This student found that face-to-face PBL allows better communication among team members. The unavailability to access to the CAD software remotely limited the students' opportunities for collaborative design.

Discussion

The paper addresses how students' knowledge, skills and professional attitudes develop in multidisciplinary settings, particularly when working through engineering design projects in a global digital environment compared with traditional face-to-face approach. The analysis of results presented in this paper focus primarily on the second round survey. The majority of the students (>50%) in this study enrolled in courses that involve both face-to-face and virtual design projects, and their level of engagement and learning outcomes for MIET2093 course that utilises digital PBL were compared with the same cohort that use face-to-face PBL.

The analysis on communication and engagement characteristics indicates that students are more likely to contribute to group discussions and engage with team members to complete the design project through face-to-face approach. The majority of the students (>65%) were exposed to a virtual platform to perform collaborative design for the first time, and they indicated that they had to devote more time and extra practice in order to get the most out of the digital environment, and believed the time and efforts often outweighed the benefits. They also found the use of digital environment challenging, particularly with unstable internet connections, limited access to computer labs and with no access to the virtual platform remotely. It is not surprising that the majority of students would prefer to use face-to-face discussion frequently when they: (i) could share in depth and in person; (ii) could avoid miscommunication through text; and (iii) could reach an agreement and make a shared decision without delay. These insights are useful for educators to address: (i) how practice is the key to master in virtual collaborative design; (ii) how to motivate students to engage emerging technologies used to manage engineering design process; (iii) the potential misconceptions of the technological difficulties and challenges of the virtual environment.

It is important to note that most of the students are transitioning from high school to first-year university programs. They have been exposed solely to traditional classroom environments. When these students are exposed to the virtual platform for the first time, they will not readily have the technological skills for the digital environment. As indicated in a previous study, students must be guided, prepared and motivated in order to implement the use of digital platform successfully (Akili, 2010).

Despite the perception of the technical difficulties of using the digital platform, students thought their collaborative design experience through digital platform was positive. They saw the usefulness of the digital platform that helped the development of new skills to create and explore of virtual 3D models, addressed a systematic engineering design process, and accessed data and generated solutions on a single virtual platform.

For the three PBL projects, all groups had to gather relevant information to solve design problems. Further analyses on the free text feedback indicates that when the group members found it hard to access the virtual platform off-site, and when members were slow in responding online, they began to use face-to-face discussions. In line with a previous study, students found face-to-face discussions helped the group members to communicate in a timely manner (Yeh, 2010). Indeed, face-to-face and virtual collaborative design approaches are complementary, and the good use of both can facilitate problem-solving (Yeh, 2010).

Due to the diverse nature of our students from multidisciplinary (aerospace, mechatronics, system engineering, manufacturing), multicultural (Eastern, Western, Middle Eastern) and multilingual (English speaking and non-English speak) backgrounds, effective communication is very important for collaborative success. Students indicated that communication could often be problematic within the digital platform—especially when the message was not explicit or direct.

With increasing globalization, stakeholders need to communicate on an almost daily basis with people from different cultures, developing the abilities and skills to communicate effectively across cultural boundaries, and this is a key to global success and to avoid misunderstanding (Nardon et al., 2011; Lisak and Erez, 2015). In order to avoid misunderstanding, team members should have a common framework and regular feedback (Zhang, 2011; Gogan et al., 2014).

Conclusion

The analysis on communication and engagement characteristics indicates that students are more likely to contribute to group discussions and engage with team members to complete the design project through face-to-face approach as compared with the virtual platform. The reasons were majority of students were exposed to the virtual platform for the first time and they had to devote more time and extra practice in order to improve their technological skills for the digital environment. They believed the time and efforts learning to use the digital environment often outweighed the benefits. They also found the use of digital environment challenging, particularly with unstable internet connections, limited access to computer labs and with no access to the virtual platform remotely.

Despite the perception of the technical difficulties of using the digital platform, students saw the usefulness of the digital platform addresses a systematic engineering design process and solution on a single virtual platform. If appropriately implemented and delivered, PBL in virtual environments can be an effective way to improve technical and communication skills in engineering graduates. This paper reports on the findings of students' collaborative design experience using a digital platform and a traditional face-to-face approach in engineering courses. Our intention is to assist improving the teaching the students received and learning they engaged in. In general, students thought their collaborative design experience through a digital platform in this project was positive. To capitalise on what we have learnt, three key aspects of the virtual environment need to be further explored: (i) educators must value and learn from students' experience; (ii) students should be encouraged and motivated to practise and become familiar with the functionalities and capabilities of a digital platform; (ii) Universities need to invest in adequate level of facilities to this level of teaching and learning.

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