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Students' Perceptions of Problem-Based Learning in Multidisciplinary Groups When Seeking to Solve an Engineering Grand Challenge

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ABSTRACT

This paper presents findings from a small-scale research study eliciting students' perceptions of benefits and challenges of working in interdisciplinary groups to solve an engineering challenge using problem-based learning. Penultimate and final year undergraduates and postgraduate MSc students in the School of Engineering and Physical Sciences at a Scottish university, studying Robotics, Mechanical, Chemical, Electrical and Software Engineering worked in interdisciplinary groups of five on a project to provide solutions to the United States National Academy of Engineering Grand Challenges (NAEGC). Students were surveyed twice, using closed and open questions before and towards the end of the project. Data were analysed using a thematic approach. Findings showed that most students saw benefits to problem-based working with students from other disciplines, citing increased awareness of approaches, future 'real world' professional preparation and efficiency in problem solving. However, challenges around scheduling meetings and concerns around cross-discipline collaboration indicate that universities should provide training for students before undertaking such problem-based projects, to ensure maximum educational benefits. In addition, greater emphasis needs to be put on students' awareness of the added benefits of development of the 'soft skills' needed for future professional practice.

Keywords: Problem-based learning; interdisciplinary group work; students' perceptions; preparing for professional life

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INTRODUCTION

This paper presents the findings of a small-scale research project which explored engineering students' perceptions of working collaboratively across disciplines on a problem-based learning (PBL) project to address a United States National Academy of Engineering Grand Challenge. Students worked in small interdisciplinary groups and responded to two questionnaires, one before the group project started and one towards the end of the project, noting their perceptions concerning a number of areas related to collaborative working in responses to a mix of closed and open questions. The findings indicate that, while students recognised many benefits to working as part of an interdisciplinary team to resolve a problem, a number of negative comments indicated that it could be helpful to provide training for students before they start working collaboratively to maximise educational and future professional outcomes. The findings will be of interest to those responsible for organising problem-based courses in Engineering Faculties where an increasingly integrated approach is being encouraged (Mora et al., 2019).

Working collaboratively

Collaborative learning is based on Vygotsky's constructivist principles (1978, 1986) which emphasise the importance of the co-construction of knowledge through discussion with a 'more knowledgeable other' who can be a teacher or a peer, underlining the social aspect of learning through dialogue (Mercer, 2000). It has been suggested that the social interaction taking place during the implementation of a task may be an important part of learning (Bransford, Brown, and Cocking 2000). Mattessich, Murray-Close and Monsey (2001, 7) define collaborative learning *as 'a mutually beneficial and well-defined relationship … to achieve common goals. The relationship includes a commitment to … shared responsibility, mutual authority and accountability for success, and sharing of resources and rewards'.*

As far back as the 1980s, it was argued that collaborative learning is more effective than more didactic approaches, because students are likely to learn more and retain the information longer through the discussions they have to solve problems (Collier 1980; Cooper 1990). In the present day, experiential learning, where students' knowledge and understanding are developed through the process of the learning experiences taking place within a social-constructivist setting which provides feedback and problem solving, is increasingly recognised as advantageous to learners across disciplines and sectors (Kolb and Kolb, 2006), particularly in the Higher Education sector. Peer Assisted Learning '*... teaching and learning strategies in which students learn with and from each other without the immediate intervention of a teacher'* is considered beneficial to enable students to take responsibility to ensure that teamwork results in positive outcomes for problem solving (Boud et al., 1999: 2, Topping 2005; Keenan 2014) and is increasingly used in courses throughout UK Higher Education institutions (Capstick et al., 2004). Since the end of last century, collaborative learning has been increasingly used to resolve hypothetical issues in medical and engineering studies, where students work together in what has become known as Problem-based learning or Project-based learning (Kolmos and De Graaff, 2015).

Considering STEM subjects specifically, Tytler et al. (2019: 52) argue*: 'increasing emphasis on inquiry, problem solving and creativity in STEM curricula'* provides a way to better train students to engage with each other, as they would in the real world of work. Students may be set a task, the resolution of which may be accomplished in small groups, each person sharing responsibility for contributing to the finished product. The active learning which results mirrors professional practice in industry and is therefore seen as beneficial on an educational, practical and professional level (Göl and Nafalski 2007). Van den Beemt et al. (2020) in their review of interdisciplinary engineering education literature between 2005 and 2016, found that projects involving real world scenarios were motivational for the students who took part. McNair et al.'s research (2011) suggested that learning from other disciplines increased students' respect for what they had to offer in a team, underlining the changes in '*thinking, acting and being'* that Adams et al. (2010: 558) suggest take place as a result of working across disciplines. It appears clear that the future of engineering education will need to be interdisciplinary to prepare learners for the work environment (Kapranos, 2019). Our study hoped to explore whether students had indeed felt motivated by collaborating with others and whether as a result they questioned their beliefs regarding interdisciplinary working within a problem-based scenario.

Within PBL links between theory and practice can be strengthened by reflective discussion by students in their groups (Cooper, 1990) as they focus on a product to be constructed collaboratively. Through discussion students may also develop 'soft' skills such as interpersonal skills and negotiation (Crichton and Templeton, 2013). Stigmar's critical literature review (2016) agreed that students who took part in problem solving collaborative learning developed critical thinking and communication skills. *'Learning to work together in a group may be one of the most important interpersonal skills a person can develop since this will influence one's employability, productivity, and career success'* (Johnson and Johnson, 1989: 32). In addition, working in small groups can enhance intercultural understanding (Slavin 1990) which is important when one considers the cultural mix often found in universities, and the increasingly global contexts within which future engineers will be working (Sharma et al., 2017). The university in which the study was conducted had, in fact, a number of campuses across the world (Europe, Middle East and Southeast Asia) which made the prospect of students working together even more relevant to future practice. We were interested to see whether students would mention other cultures' ways of approaching challenges.

Challenges to multidisciplinary learning

While it appears that collaborative problem solving is generally viewed as beneficial for students, some challenges have been noted. Working across disciplines results in challenges including student engagement, unequal motivators, abilities and group maturity (Hubbard and Gregory, 2011; Agyeman et al., 2019). Soares et al. (2013) noted a need for greater support for students than their lecturers had assumed they would need. Issues around 'free-loaders' and subsequent lack of trust have also been identified (Borrego et al., 2013), resulting in some students' viewing group PBL without enthusiasm. Richter and Paretti (2009) talk of 'negative relatedness' which refers to students' limited ability to recognise either the contribution that they can make to problem solving drawing on their own discipline, or that of others. Practical issues such as timetabling across different disciplines are also viewed as potentially causing students to struggle to find a time to meet (Gombrich, 2018). Students' time management skills may also be under undeveloped (Sharma et al. 2017) exacerbating difficulties of finding a time to meet together. Our study aimed to identify any challenges that students experienced, with a view to addressing them in future project-based tasks.

THE STUDY

As already noted, this small-scale research study aimed to gain students' perceptions of working in interdisciplinary groups as they collaborated to propose a solution to a United States National Academy of Engineering "Grand Challenge for Engineering". Although originating in the United States, the fourteen Grand Challenges are supported by the national engineering academies of the United Kingdom (the Royal Academy of Engineering) and the People's Republic of China (the Chinese Academy of Engineering), thus giving them global relevance.

As the Grand Challenges are very broad in their overall scope, a subset of eight Grand Challenges was used to better reflect the individual subject disciplines taking the course. The Grand Challenges were randomly allocated to the groups. The interdisciplinary PBL project therefore provided an opportunity for students from the subject disciplines to apply their discipline-specific knowledge and skills to a common project.

Participants

This course, entitled Professional and Industrial Studies, was mandatory for all participating students. The 220-strong cohort under study comprised undergraduate Integrated Masters students from Robotics, Mechanical, Chemical, Electrical and Software Engineering and postgraduate Mechanical Engineering students. The students not only came from a wide variety of STEM disciplines, but also a variety of locations, as some were based at the university's overseas campuses, or in overseas partner universities.

The course is led by academics from Chemical Engineering and Mechanical Engineering. The course leader had extensive industrial experience before joining academia, and redesigned this course, including introducing the interdisciplinary PBL project, to help better prepare students for the types of work they may experience in a professional engineering environment after graduation.

All of the students taking this course were from subject disciplines which are accredited by professional engineering bodies in the United Kingdom, for example the Institution of Chemical Engineers, the Institution of Mechanical Engineers and the Institution of Engineering & Technology. The programme learning outcomes defined by these accrediting bodies have a strong focus on open-ended PBL projects, teamwork, communication (see for example IChemE 2021). Chemical engineering students, for example, undertake subject-specific group-based PBL projects in all five years of their integrated masters programme, with 20% of the final degree award based on two major group-based projects in years 4 and 5 of the programme.

The majority of the cohort had therefore had experience of working in groups as part of their subject discipline studies, however, few had prior experience of working in interdisciplinary groups on a problem-based project. Our initial aim in conducting the study was to collect data which could indicate directions we might pursue to improve the course for future cohorts. We were keen to determine which benefits, if any, students perceived from working in such diverse groupings of disciplines and what they saw as challenges or potential barriers to successful collaboration. Our research questions, therefore focused on the students' experiences of the course:

- What do students see as advantages of working together across disciplines in the Professional and Industrial Studies course?
- What challenges do students perceive to working collaboratively on a problem-based project?

Data Collection

All the students were emailed, telling them the purpose of the research and asking them if they would be willing to participate by completing two questionnaires, one at the beginning and one towards the end of the course when students were coming together to finalise their response to the task, to gain their perceptions of working in interdisciplinary groups, before and after doing so. Ethical approval was sought from the university before conducting the survey. We were aware of our responsibilities as the students' tutors and the potential power issues that may arise when conducting research with one's students. We bore in mind Mitchell's (2004) assertion: *'… the sorts of data collection that require student assent are very likely to fail to give useful data if there is any perception (let alone reality) of coercion'*. (p. 1430). Students were assured that they were not obliged to participate and could withdraw at any time. They were promised that every effort would be made to ensure their anonymity as the research would be conducted according to the British Educational Research Association guidelines (BERA, 2019) which stresses the rights and well-being of participants. It was also stressed that non-participation would have no influence on grades.

Out of the 220, 30 students responded to the first survey (14%); 45 responded to the second survey (20%). 11 students responded to both surveys (5%). While the response rate might be considered disappointingly low, student responses can be as little as 14% (Porter and Umbach, 2006). It is possible that the low numbers of respondents to the first questionnaire were because they felt unable to answer what to them were hypothetical questions about working in groups than the greater number who responded to the second questionnaire after doing so for six weeks. Details of the surveys are discussed below.

The Questionnaires

Surveys have been described as *'the collection of information from a sample of individuals through their responses to questions'* (Check and Schutt, 2012: 160). The questionnaires comprised a mix of closed and open questions which centred round students' perceptions of the importance of different aspects of interdisciplinary teamwork. The questionnaires were sent to the students in week 2 of the course and then again in week 8, towards the end of the course. We used Online surveys (onlinesurveys.ac.uk), an online survey tool created for academic research, to design the survey. One of the advantages of using this platform was its availability to academics in different institutions, as well as being GDPR[1] compliant. Aware of the demands on their time, we designed the questionnaires to be relatively short so that students would not be put off by a lengthy survey (Lowe and Zemliansky, 2011). Students responded to the five closed questions about the perceived importance of different aspects of teamwork, such as academic ability, enthusiasm, topic, group members' discipline etc. by selecting a point on a 5-point Likert agreement scale (Likert 1932) which ranged from 'not at all important' to' very important'. The final three open questions were related to students' perceptions of benefits or disadvantages of interdisciplinary teamwork and required them to respond in their own words. Care was taken to ensure that the language of the survey was objective and non-leading (Fink, 2002), so that students would respond without any influence.

Analysis

The survey data were analysed qualitatively, despite the use of Likert scale items, which might be considered more appropriate for quantitative analysis . *'If one uses numbers,* *interpretation is still involved.'* (Bazeley, 2004:2). *'…simple counting techniques can offer a means to survey the whole corpus of data ordinarily lost in intensive qualitative research. Instead of taking the researcher's word for it, the reader has a chance to gain a sense of the flavour of the data as a whole'.* (Silverman, 2006:52). While counting the number of responses in each category for each item gave a picture of the general trends, by scrutinising the open questions, which often appeared prompted by the responses to the closed questions, we were able to interpret the graphs generated by the Likert scale responses to gain a more nuanced picture of the students' perceptions related to their experiences.

The analysis aimed to detect common themes arising from students' reflections on their experiences of PBL considering their different perspectives (Willis, 2007). General inductive approaches are often used by researchers in the social sciences (Thomas, 2006) but were deemed appropriate for this study which was conducted in an engineering context, as it focused on student perceptions. After continuously rereading the data before agreeing a coding frame, we individually identified recurring patterns, which were then reviewed and refined into clear themes. We hoped that, by interrogating the data individually in the first instance, no important insight might be lost and that all relevant categories identified could be justified within the discussions taking place subsequently, so a collaborative interpretation of the data could be agreed (Cornish et al., 2014). We used Braun and Clarke's Thematic Approach to thematic analysis (2006) in order to be able to provide as much detail of the participants' realities as possible in such a small-scale study, constantly revisiting the data before identifying, reviewing and defining the themes and patterns occurring which allowed us to make sense of the Likert-related graphs.

Although the sample could be considered small and the students came from a wide variety of disciplines, the responses indicated some clear themes regarding their perceptions of interdisciplinary working which will be discussed in the findings section below.

FINDINGS

As we were interested to find out whether students' perceptions of collaborative working within a PBL environment changed over the course of the project, findings from both surveys will be discussed where appropriate. There were some areas which showed little change in perception from the beginning of the course, however, there were some findings which demonstrated a significant change in students' mindsets after working collaboratively. Each area of the questionnaire will be discussed below, with quotes from the open questions to support our interpretations of the data.

Benefits of interdisciplinary working

One of the most positive aspects of the findings was that the majority of students who responded in both the initial and second surveys said that working together across disciplines was beneficial. 80% of students in the second survey indicated that they had found PBL working across disciplines very or somewhat beneficial. Interestingly, when they had been asked in the first survey whether they thought that group work was beneficial in their courses 91% agreed. The dip in percentage points may have been because mostly different students responded to the second survey than to the first but may also have reflected challenges that the students had faced in the practical organisation concerned in this particular course. The 11 students who completed both surveys indicated very little difference in perception from the first to the second survey. In the open questions in both surveys, students cited the importance of sharing different perspectives to problem-solving: '*Different sets of skills from different principles helped solve problems that could not be solved from one discipline'.* A large number of responses to the open questions referenced future career prospects: *'…it felt like an actual working environment'; 'this multi-disciplinary group project is an ideal course for final year engineering students as it the most similar a course could be to real industrial engineering projects, … before heading into our careers'.*

Most students expressed confidence in working collaboratively to solve a problem (79%). This may have been because a large majority had already done so previously in their university studies (89%), professional placements (29%) and/or personal activities (42%). It seemed that they were already accustomed to working as part of a team, and therefore were well-disposed to the task they were assigned.

Ease of collaboration

In the first survey, students were asked to compare the prospect of multidisciplinary PBL collaboration with previous group work they had undertaken in their studies. 50% said they thought it would be harder. However, after the collaboration had taken place, this had dipped to 38%. The number believing that there would be no difference between working in an interdisciplinary team as regards a subject specialist team stayed relatively stable (31% in the first survey to 29% in the second). In the first survey only 17% of students thought it would be easier. However, in the second survey 33% stated that it had been much or somewhat easier than they had anticipated. Responses to the open questions indicated that the mix of disciplines had been useful in the completing the task: *'I feel that we are more efficient in the multi-disciplinary group'. 'The opportunity to work with people from other backgrounds helped with having a range of knowledge to source from…'* Some students stated that they had gained in knowledge from working with other disciplines: *'A wider range of knowledge across the group is achieved'.* Clearly a shared responsibility for the task with each group member influencing decisions according to their knowledge had contributed to a feeling of satisfaction in the process. As noted above, benefits for students working together on problem solving and/or providing peer feedback are widely recognised (Boud et al. 1999, Topping 2005; Keenan 2014). Lower levels of anxiety, increased confidence and communication skills are seen as a result of collaborative group work (Keenan 2014).

Contributing factors to success of PBL interdisciplinary working

The students had been asked specifically what they felt contributes/contributed to effective groupwork, as this was an area that we were keen to explore with a view to improving provision for subsequent cohorts undertaking PBL. An overwhelming majority of students cited the importance of individual academic ability in the first survey (90%) along with individual enthusiasm for the project (96%) as main contributors to effective group working. However, in the second survey these figures had dropped to 49% and 76% respectively. While individual enthusiasm was still rated relatively highly, group members' academic ability was seen as much less important after the task had been completed. It is possible that the students' discussions had made them assign greater importance to taking different perspectives into account, allowing them to think more laterally, than relying on a purely academic approach. Nonetheless, responses to the open questions showed that group members' academic ability was still valued: '*Better variety of specialist knowledge.' 'Some technical details can be better understood when explained by a group member that has seen it before'.*

In both surveys, students appeared to agree that the focus of the problem to be solved was an important indicator of potential success. The mix of group members' disciplines were also seen as contributing to the success of the project: '*Different sets of skills from different principles helped solve problems that could not be solved from one discipline.'* In the open questions most students praised the teamwork and commitment of their group members, who had worked to build good relationships and communication skills when sharing knowledge. Although the students made the link to future working practices, when they would be expected to work across disciplines, they did not appear to recognise that the assignment could also be seen as developing those qualities so important for teamwork in the work environment. It seemed that they were more focused on completion of the project, rather than connecting it to their own development of 'soft skills' so valuable for successful collaborative problem solving.

Perceived challenges to PBL interdisciplinary working

Although the overwhelming response by the students was positive, there were important challenges to meeting the brief of the project that students identified. Approaching the task from different perspectives was generally seen as a good thing. However, when it restricted people's thinking regarding processes and procedures, some students experienced frustration*: '... disagreements on methods to solve an issue due to different* *perspectives.' 'The main difficulty I have found in multi-disciplinary group work is trying to prevent group members input being too technically focused on their own discipline fine details and not the more general project objective.'* One student noted that they were the only one in their discipline in their group and therefore felt their suggestions were overridden by others, while two students observed that their groups appeared biased towards one particular discipline, which also created a perceived imbalance of power within their groups with regard to decisions.

Some students mentioned the need to organise other, less focused students: *'I have to work harder than ever to get my group to talk to each other'. 'I have to push my team members to give their opinions in meetings'.* While drawing other students' views out may have seemed onerous to those students, although they had not recognised it, they were developing the type of leadership skills necessary for project completion, which they could take forward in the workplace.

One of the biggest challenges for students appeared to be finding a time to meet to discuss their project: *'there can be several timetable clashes between all the courses.'.* Almost all the students mentioned issues with scheduling meetings. Some students had competing deadlines, so prioritised what they saw as more important: *'Some people may prioritise other subjects over this one'*; the multiple campuses in different time zones, as well as students' other commitments also created scheduling challenges: *'our group is working over 4 timetables and 2 time zones and several part time jobs'.* It should be noted that this course was undertaken remotely under lockdown conditions, as a result of the Covid-19 pandemic, so it is possible that students actually had greater flexibility to arrange meetings at times which suited everyone. It might be argued that agreeing a schedule of group meetings could be beneficial for the development of students' time management skills (Costa et al., 2019), as well as the negotiation skills necessary for working effectively in industry (Gray, 2016).

Development of their negotiating skills was also deemed essential by a small number of students who had felt frustrated by some members' insularity. Despite favourable comments about the range of academic backgrounds from most of the students, it seemed that the mix of disciplines could also result in discord: *'There are disagreements on methods to solve an issue due to different perspectives'.*

A further challenge was presented by those students who might be considered what Aggerwal and O'Brien term 'social loafers' (2008), that is, those who contribute little to the project: *'not pulling their weight'.* Sometimes this appeared due to the conflict of students' perceived priorities and poor time management, as noted above: *'... sometimes group members would not do their assigned parts because of deadlines'*, but some students cited a lack of their group members' engagement which was discouraging*: 'At the moment it honestly feels like a solo project'*

DISCUSSION

It could be argued that the very name of the course, Professional and Industrial Studies, suggests links to industry and the professional workplace and it is therefore no surprise that the majority of the students themselves made the links, for the most part approving of the course and its interdisciplinary, PBL nature. While they acknowledged that each discipline had different ways of approaching problem-solving and report writing, they also appreciated the opportunity to try different ways to tackle the brief: *'... experience of group work and report writing varies from discipline to discipline meaning that this brings variation to the project approach in terms of research, presenting and reporting.'* Despite the strong positive responses from most students, who cited future career benefits and wider understanding of problem-solving strategies among other advantages, it seems clear that there were some issues arising from the multi-disciplinary project, which proved frustrating and discouraging for some of those who responded. As can be seen in the findings, problems with collaboration occurred in the face of intransigence or work avoidance on the part of some group members.

Mattesich, Murray-Close and Monsey (2001) identified six factors which they claim influence collaboration positively. These include a common purpose, shared governance and joint decision making, clear understanding of roles and responsibilities and open and frequent communication, as well as trust and adequate resources. It seems that assumptions may have been made not only by university staff when setting up the course, but also by the students themselves regarding student engagement and the understanding of their roles and responsibilities. Subsequent interdisciplinary projects would benefit from a clear set of explicit expectations, based on Mattesich et al.'s factors, that are shared with both participating students and supervising staff and discussed before the project starts, so that everyone is aware of the importance of their role as well as their responsibilities to their group. While wishing to encourage autonomy in collaborative teams, regular 'check-in' opportunities may also be beneficial for students to provide an update of their progress, in the form of a running report, for example, which could be monitored by supervising staff and also be seen as motivating those students less inclined to contribute fully. Issues which were mentioned regarding subject bias within groups could be easily addressed by creating a simple formula to ensure that one discipline does not constitute a majority of group members, so that decisions may be more democratic and 'cliques' of disciplines are not created (Bacon et al., 2001).

CONCLUSIONS

A large majority of students approved of the interdisciplinary PBL collaborative project, citing advantages for their future working environment as one of the main benefits. Most of them also said they enjoyed working in partnership with other students from a variety of disciplines, as it developed greater understanding of different approaches to achieve resolution to challenges. Although they also mentioned some frustrations, only one of all the students who responded felt that they had gained nothing from the course. Interestingly, although students commented on the difficulty of arranging meetings across time zones with regard to those studying in the overseas campuses, there were no comments about cultural issues regarding understanding or ways to approach a problem. It seemed that the only cultural element which arose in the groups related to the culture of the actual discipline that students were studying, which appeared to influence how they approached the brief.

It was clear from the students' comments that the majority of them had developed the soft skills of interpersonal communication and negotiation, so important to the successful conclusion of any problem-based project, to work through frustrations to find solutions. Some had felt compelled to take a leadership role encouraging others' contributions, while others had had to be more organised with regard to time management. However, very few of the students mentioned the growth of these interpersonal aspects of teamworking as a positive factor in their development, preferring to focus on the final product. It may be that greater work needs to be done to make students aware of the wider social and professional benefits of interdisciplinary PBL collaboration, so that they can actively practise their interpersonal communication and negotiation skills in this type of project, seeing this as an important consequence of their discussions, which they can also take forward in their future careers.

This study was small-scale and cannot be held as representative of the wider STEM cohort in universities who take part in interdisciplinary PBL collaborative projects. The disappointingly low number of students who responded to both questionnaires means that a valid comparison regarding perceptions before and after the course cannot be made. However, our research does raise some interesting points which would benefit from further larger scale investigation.

The questionnaires did not identify whether the students who responded were final year undergraduate or postgraduate students, and thus we were not able to determine whether there was a difference in perceptions, perhaps as a result of greater experience or maturity (Hubbard and Gregory, 2011).

In planning the research, we were aware of students' workloads and time pressures and decided not to ask them to participate in focus groups or individual interviews. With hindsight, the findings could have been more rigorously validated had we done so and certainly in future research into collaborative interdisciplinary PBL working, we will use the findings from this study as a basis for further exploration of the issues arising.

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[1] General Data Protection Regulation (GDPR) refers to European Union legislation enacted in 2018 that protects consumers' and private citizens' data.