Teaming with Confidence: How Peer Connections in Problem-based Learning Impact the Team and Academic Self-efficacy of Engineering Students

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Abstract

Engineers will routinely work in teams to solve complex problems. Team-working and collaboration are therefore an integral part of engineering education as they offer enhanced opportunities of acquiring both transferable and subject-specific skills.

This paper examines the experiences of third-year engineering students studying a design-based module which uses problem-based learning (PBL) as the main pedagogical approach where students work in teams of 5 or 6 to achieve the associated learning outcomes. PBL allows students to not only play an active role in their own learning but also affords the added opportunity of learning with and from each other (peer learning). The success of this experience can however, be impacted by the team efficacy which exists or ensues as part of the process. These interactions can influence academic self-efficacy and a key aim of this paper is to use the students' perceptions of their experiences with PBL to examine the relationships which exist among academic self-efficacy, peer learning and team efficacy within the module.

Findings show that a large percentage of students (85%) felt they learned from each other and that this collaborative experience strongly improved their understanding of mechanical design principles. Self-efficacy scales ranging from 0 (cannot do at all) to 100 (highly certain can do) showed that 65% of students rated their average academic self-efficacy across all learning outcomes as high (above 75). This efficacy was positively related to the support received from peers. Only 6% of respondents indicated that they would be confident undertaking the module by themselves and that while peer-to-peer interactions helped with sharing the workload and producing deliverables, they would have been able to successfully tackle the module alone had the time allotted been increased proportionally.

This information is valuable as it can inform and direct future module design within our programme in which many modules are team-based. This could involve and lead to the introduction of new- and the strengthening of existing peer learning opportunities which could transform the way we teach and learn in our department.

Introduction

The real-life experiences of engineers working in multidisciplinary teams to solve complex problems can be replicated in a classroom setting using problem-based learning (PBL). PBL is a student-centred approach in which students achieve their learning outcomes by working in small teams to solve an authentic and complex problem [1, 2]. In PBL, the onus is on the learner to be responsible for his or her own learning and to take a proactive role in the learning process [3]. This principle, when coupled with the team and peer-to-peer interactions that PBL affords, allows opportunities for peer learning in which students learn

with and from each other [4]. Peer learning is a type of collaborative learning where students work in pairs or small groups to find solutions to problems [5].

The success of this experience can however, be somewhat impacted by the team efficacy (performance) which exists or ensues as part of the process. Several studies [6 - 8] have suggested that selected team attributes (e.g. poor communication, overly assertive team members and low group cohesion) can limit the effectiveness of the PBL approach. This can reduce the strength of collaborative learning and can also influence a student's academic self-efficacy [9].

A high level of academic self-efficacy means that a student has a high confidence that he or she will be able to successfully complete an academic goal [10, 11], which is independent of the actual performance or grade achieved. How a student believes they will perform academically is often as, and sometimes more, important towards sustaining academic motivation than just attaining the academic target itself.

These ideas form the rationale for this study and a key aim of this paper is to use students' perceptions of their experiences with PBL to examine the relationships which exist among peer learning, academic self-efficacy and team efficacy specifically within the context of the Mechanical Design Project module taught to chemical engineering students at Imperial College London (ICL).

The MEng Chemical Engineering programme at ICL is currently undergoing a review of its curriculum and we believe that this study and its results would be valuable to inform and direct future module design within the programme in which many modules are team-based. This could involve and lead to the introduction of new- and the strengthening of existing peer learning opportunities which could transform the way we teach and learn in our department.

The role of academic self-efficacy, peer learning and team efficacy within PBL

The use of PBL in engineering education is widespread [7, 8, 12 - 15]. In PBL, real-life problems are presented as the stimuli to learning and students work in small groups to solve these complex real-world problems. Students are required to continually work at the higher levels of Bloom's taxonomy of educational objectives as they collect, evaluate and synthesise information [16].

Given that the problem is complex and presented to students without formal instructions on how to solve it, students will often be required to learn new and unfamiliar concepts using a variety of collaborative approaches, such as peer learning. Peer learning refers to students, generally of the same class or cohort, learning with and from each other [4]. The strength of peer learning can be explained using the perspective of Vygotsky's Zone of Proximal Development which compares what a student can learn independently to what he or she can achieve through the help and guidance of an expert (who does not necessarily have to be an adult) [17, 18].

Vygotsky [18] contends that the value of peer learning rests with students, particularly of the same age group, being able to better function within one another's zone of proximal development. Within this context, fellow students become primary knowledge facilitators [19] and can "learn a great deal by explaining their ideas to others and by participating in activities in which they can learn from their peers" [17, p. 3]. Collaboration with fellow students has been shown to be a consistent means of increasing knowledge and understanding [20].

Although there is prevalent evidence in the literature to support the existence of collaborative learning when PBL is used [4, 17], the cooperation among students (which gives rise to peer learning) is not necessarily a natural occurrence or given outcome of group work [21]. Several problems can exist when students work in teams [22] which can lead to the development of dysfunctional groups [23].

Norman [24, p. 820] states that dysfunctional groups are the 'Achilles heel of PBL' and often display distinctive behaviours which inhibit the success of small group learning. These behaviours include a lack of cohesion, poor team relationships and interactions, reduced internal problem-solving skills and a lack of motivation [25] which can severely undermine team effectiveness and the achievement of peer learning. The success of the PBL experience therefore depends strongly on group functioning [23] and it becomes important for educators using PBL to be mindful of the issues that influence group dynamics in order to foster effective team performance and respond to the challenges faced by dysfunctional groups.

Academic self-efficacy can be defined as a student's judgement of his or her own capability to successfully complete given academic tasks [10, 11]. The importance of academic self-efficacy is related to the idea that students who perform well at challenging assignments with limited help will increase their levels of self-efficacy and that they will continue to attempt and persist with tasks of increasing difficulty, more frequently even in the face of failure [26]. Jerusalem and Schwarzer [27] and Pintrich and De Groot [28] further contend that these individuals have a greater belief in their abilities to overcome obstacles and tend to be more solution-driven, focusing on opportunities instead of limitations.

These ideas readily support and underpin the aim of learning approaches like PBL. Hmelo-Silver *et al.* [29] contend that the outcomes of PBL are multifaceted and that the goals of learning should not be restricted to only assessing technical knowledge but should also include the development of flexible thinking and the preparation of students to be adaptive experts. Dunlap [9] goes on to state that PBL serves as a source of self-efficacy for students and that their experiences of success can adequately prepare them for their chosen professions.

In terms of PBL success, students often have their own ideas of what contributes to an effective learning experience and although academic self-efficacy, peer learning and team efficacy within PBL has been presented in many studies [4, 9, 17, 29], their existence and role depend to a large degree upon the individual learner and the cohort to which PBL is applied. This work therefore investigates these three variables specifically within the context of the Mechanical Design Project module taught to chemical engineering students at ICL.

Module Organisation and Delivery

The Mechanical Design Project is a core module taught to third-year undergraduate students who are undertaking their MEng in Chemical Engineering degree at ICL. The module is delivered across 2 student-cycles each lasting 2 weeks. Each cycle comprises approximately 50 – 60 students who work together in randomly-assigned teams of 5 or 6 across eight 3-hour sessions (a total of 24 hours contact time) within the 2-week period.

Within this timeframe, students must design a pressure vessel for a selected industrial use in accordance with the requirements of the Published Document 5500 (PD5500:2018). This is the UK's code of practice for the specification of unfired fusion welded pressure vessels which is similar to the ASME Boiler and Pressure Vessel Code used throughout the USA.

Students must be able to justify key features of their final designs (including size, shape and orientation) and be able to show and defend their design calculations for each part of the vessel (including ports, supports and relief valves). These should clearly demonstrate that no part of the vessel is subjected to a stress in excess of the maximum allowable stress for the chosen material of construction.

The main module deliverables are a set of documents which comprise a team report and a set of drawings where each member of the team produces an individual 2D drawing which has a different view of the vessel. These are used to summatively assess the key learning outcomes of the module which include a working knowledge of the appropriate codes, the completion of the mechanical design of a pressure vessel and the ability to represent these designs using general assembly drawings.

Research Questions

Students often have their own ideas of what contributes to an effective learning experience. They are the co-creators of their own learning [30] and understanding their perspective has been shown to influence and enhance reflection-on-action practices [31]; this can allow practitioners to reflect and review past practice with the purpose of improving future scholarship. Feedback from student evaluation questionnaires can accordingly imbue the student voice with a power and agency to inform reflection-on-action practice which can help further enhance staff development and curriculum review [31].

For this reason, we focus primarily on the students' perceptions of their experiences within their Mechanical Design Project module and use this to examine the following research questions:

1. To what extent do students believe that their interactions within this module have resulted in academic self-efficacy, peer learning and team efficacy?
2. How does team efficacy impact peer learning and the academic self-efficacy of students within this module?

Research Methodology

Our research questions were examined using an anonymously self-administered (online), semi-structured questionnaire which evaluated students' feedback at the end of their Mechanical Design Project module. Twenty-five closed-ended descriptors were used to map and measure the three main constructs of academic self-efficacy, peer learning and team efficacy. Table 1 shows the individual descriptors for each of the constructs.

Table 1: The constructs and descriptors used to examine our research questions

Construct	Sub-construct	Descriptors
Team Efficacy	Cohesion and Commitment	1. My team members wanted to be on our team. 2. I wanted to be on our team. 3. My team members frequently went beyond what was required and did not hesitate to take initiative. 4. My team members clearly understood their roles and were committed to completing this project. 5. My team acted as a cohesive unit
	Team Processes and Decision-Making	6. Team problem solving resulted in effective solutions. 7. My team was able to make thoughtful decisions that all team members supported. 8. My team members followed through on decisions and action items. 9. My team members were held accountable for their responsibilities and assignments. 10. My team members were encouraged to express different points of view.
	Team Relationships and Communication	11. My team members expressed disagreements constructively. 12. My team members are effective listeners. 13. Communication in our team was open and honest. 14. My team members helped one another deal with problems or resolve issues.
Peer Learning		15. Working in my team positively impacted my knowledge of mechanical design. 16. It was easier to learn some mechanical design principles from my team members than if I were studying these by myself. 17. During the module, I helped my team members better understand some mechanical design principles. 18. Working with my team made me more confident to undertake this project. 19. Given only 2 weeks, I feel as though I would not have been able to do this project without my team. 20. If given enough time and resources, I feel as though I would be able to successfully complete this project by myself. 21. Even if I were given enough time and resources to complete this project individually, I would still prefer to work in a team.
Academic Self-Efficacy		22. I can use selected British Standards and other relevant codes of practice to design a pressure vessel. 23. I can draw a selected 2D view of a pressure vessel. 24. I can work effectively in a team. 25. I can demonstrate effective time-management and leadership skills.

The metrics to study team efficacy were based on the work of Brewer and Mendelson [32] and Mujika *et al.* [33] and resulted in team efficacy being comprised of three sub-constructs that included cohesion and commitment, team processes and decision-making, and team relationships and communication. The individual descriptors used to measure these three sub-constructs were modified from the '20 Questions to Ask Your Teams' survey instrument

developed by Kuras and Moran [34]. Our study also adapted efficacy survey instruments from Bandura's Guide for Constructing Self-Efficacy Scales [35] to develop academic self-efficacy descriptors aligned specifically to the module learning outcomes.

After critically reviewing the peer learning survey instruments available in the literature, it was felt that developing a singular set of peer learning descriptors specifically designed for this study would better reflect the module design and aims of this work.

The strength of the students' experiences related to team efficacy and peer learning was measured using a 7-point Likert scale (where 1 indicated an extremely negative rating and 7 an extremely positive rating). Academic self-efficacies were measured through efficacy scales ranging from 0 (cannot do at all) to 100 (highly certain can do).

In addition to the three constructs of academic self-efficacy, peer learning and team efficacy, students were also asked to comment on and rank their modes of communication throughout the module when not in class. Three open-ended questions appended to each of the constructs also invited students to share additional comments or perspectives related to their experiences.

Results and Analysis

The questionnaire had a response rate of 41% (44 respondents out of a class size of 108 students). While there is no universally-accepted value, a higher response rate (greater than 50% [36]) is typically favoured because it minimises non-responder bias and preserves data quality [37].

Although low, our response rate of 41% is within the 20 – 47% range of values (average 33%) that have been quoted for online surveys [38] and while there may be uncertainties regarding representativeness, we believed that the statistical analysis of the questionnaire responses yielded fruitful information that could add to the body of knowledge surrounding peer academic self-efficacy, peer learning and team efficacy and be particularly useful to our degree programme.

IBM® SPSS was used to analyse the results of the questionnaire which included a descriptive analysis, the internal consistency or reliability of the descriptors (using Cronbach's alpha) as well as correlations among the three constructs (using Pearson's correlation coefficient).

Descriptive Analysis of the Constructs

Table 2 shows the descriptive analysis of the three constructs which includes the minimum, maximum and mean values as well as the skewness and kurtosis. The constructs of peer learning and team efficacy are measured on a 7-point Likert scale. Table 2b provides the designations of the Likert scale and show that the mean values of 6.3 and 6.1 respectively for team efficacy and peer learning indicate that students firmly perceived that their team interactions within the module resulted in high levels of team efficacy and peer learning.

This is further highlighted by the negative skewness values which indicate that the distributions are skewed towards the larger positive designations (of Agree and Strongly agree) which further support the high mean team efficacy (6.3) and peer learning (6.1) perceptions. The relatively high values of kurtosis (which is essentially a measure of the peakedness of the distribution) indicate that these two variables have very narrow peaks which is not unexpected given the narrow ranges between the minimum and maximum responses for both these constructs.

Table 2: Descriptive Analysis of the three constructs

2a. Descriptive Statistics

	No of respondents	Minimum	Maximum	Mean	Skewness	Kurtosis
Team Efficacy	44	5	7	6.3	-1.329	1.141
Peer Learning	44	4	7	6.1	-1.225	1.619
Academic Self Efficacy	44	50	93	79.2	-0.654	0.113

2b. Likert scale designations

1	Strongly disagree
2	Disagree
3	Somewhat disagree
4	Neither disagree nor agree
5	Somewhat agree
6	Agree
7	Strongly agree

Academic self- efficacies were measured through efficacy scales ranging from 0 to 100 and the results show that students rated their average academic self-efficacy as being relatively high (79.2). Although the range varies from 50 (can do somewhat) to 93 (most definitely can do), the kurtosis is quite low which perhaps indicates a bimodal distribution. Further analysis of the 44 respondents supports the existence of two populations; one group of students (65%) having high academic self-efficacies above 75 and the other population (35% of students) having lower confidence levels between 50 and 75.

Detailed analysis of individual descriptors also indicated that a large percentage of students (85%) felt they learnt from each other (Descriptor 16) and that this collaborative experience strongly improved their understanding of mechanical design principles (Descriptor 15). Only 6% of respondents indicated that they would be confident undertaking the module by themselves (Descriptor 21) and that while peer-to-peer interactions helped with sharing the workload and producing deliverables, they would have been able to successfully tackle the module alone had the time allotted been increased proportionally.

Internal Consistency (Reliability) of the Descriptors

Internal consistency or reliability refers to the general agreement between multiple descriptors (often Likert scale items) that comprise a given construct to accurately measure that construct. Cronbach's alpha is a common measure of reliability, expressed as a number between 0 and 1. Several acceptable levels of alpha values have been reported in the literature which range from 0.70 to 0.95 [39].

Table 3 shows the alpha values of the peer learning and academic self-efficacy constructs as well as the three sub-constructs comprising team efficacy; these relate back to individual descriptors provided in Table 1.

Most of the constructs show a very good general agreement among the descriptors having alpha values of 0.7 or higher (notably the three sub-constructs of team efficacy). The peer learning construct however has a borderline alpha of 0.623 which is below the lower limit of 0.7 quoted in the literature [39]. Hair *et al.* [40] contend that constructs having reliabilities between 0.6 and 0.7 are still acceptable when most of the reliability measures are above 0.7. On this basis, we accept that the individual descriptors comprising the peer learning construct provide an adequate reliability of measuring that construct.

Table 3: Internal Consistency (Reliability) of Selected Constructs and Sub-constructs

Construct	No. of descriptors	Cronbach's Alpha
Cohesion and Commitment	5	0.756
Team Processes and Decision-Making	5	0.863
Team Relationships and Communication	4	0.705
Peer Learning	7	0.623
Academic Self-Efficacy	4	0.432

There is however some concern regarding the academic self-efficacy construct which has a relatively low reliability (0.432) which is far below the recommended threshold of 0.7. A further examination of the individual constructs (module learning outcomes) which make up academic self-efficacy is provided in Table 4. This shows that the removal of Descriptor 23 (*'I can draw a selected 2D view of a pressure vessel'*) will result in an acceptable alpha value of 0.72. This is particularly interesting given that this descriptor represents an individual and not a team-based learning outcome. The implication of this is examined in more detail in the following section.

Table 4: Examining the Cronbach's alphas of the descriptors comprising academic self-efficacy

	Cronbach's Alpha if Item Deleted
22. I can use selected British Standards and other relevant codes of practice to design a pressure vessel.	0.243
23. I can draw a selected 2D view of a pressure vessel.	0.720
24. I can work effectively in a team.	0.035
25. I can demonstrate effective time-management and leadership skills.	0.192

Correlations among Constructs

The Pearson correlation coefficient, which is a measure of the strength of a linear association between two variables, was used to assess the correlation among constructs. This coefficient can take a range of values from +1 to -1, with a higher positive value indicating a stronger positive association between the variables.

Table 5 shows the correlations which exist among the three constructs. A fourth construct termed *academic self-efficacy without individual 2D drawing* has also been included based on the previous section which highlighted an improved Cronbach's alpha for the academic self-efficacy construct when the individual 2d drawing descriptor (Descriptor 23) was removed.

We can see that positive correlations (of varying strengths) exist among all constructs with stronger associations occurring between team efficacy and peer learning (0.672) and between peer learning and academic self-efficacy (0.645). These confirm what has been reported in the literature [4, 9, 17, 29] and indicate that 'better' performing teams have 'better' peer interactions which result in 'better' confidence levels.

The significance (p-value) of each correlation is also provided in Table 5. These show that the p-values between team efficacy and peer learning (0.01) and between peer learning and academic self-efficacy (0.02) are very small (less than 0.05) indicating that these correlations are significant and that these variables are linearly related.

Although there is an improved reliability of 0.720 for the *academic self-efficacy without individual 2D drawing* construct, this leads to only marginal increases in the correlations between team efficacy and self-efficacy and between peer learning and self-efficacy. This, and the associated p-values, further highlight the tenuous relationships which exist between team efficacy and academic self-efficacy in this study.

Table 5: Correlations among the constructs

		Team Efficacy	Peer Learning	Academic Self-Efficacy	Academic Self-Efficacy without individual 2D drawing
Team Efficacy	Pearson correlation	1	0.672	0.231	0.277
	Sig. (2-tailed)		0.01	0.314	0.224
Peer Learning	Pearson correlation	0.672	1	0.645	0.719
	Sig. (2-tailed)	0.01		0.02	0.002
Academic Self-Efficacy	Pearson correlation	0.231	0.645	1	
	Sig. (2-tailed)	0.314	0.02		
Academic Self-Efficacy without individual 2D drawing	Pearson correlation	0.277	0.719		1
	Sig. (2-tailed)	0.224	0.002		

Open-ended Feedback and Modes of Communication

Open-ended feedback from the questionnaire showed that interactions throughout the module also allowed for community building in other parts of the course. Following this module, students indicated that they formed informal study groups for other modules and that there

was an increased social interaction outside of the university between some team members. A survey of the main modes of communication used throughout the module also showed that students primarily used social media (mainly WhatsApp and Facebook).

The feedback also indicated that less successful experiences were had by students who perceived their groups to have lower cohesion but that these students nevertheless felt that their overall experiences with the module led to an increased academic self-efficacy.

Discussion and Conclusions

Team-working and collaboration are an integral part of engineering education. A key aim of this paper is to use students' perceptions of their experiences with PBL to examine the relationships which exist among academic self-efficacy, peer learning and team efficacy within a design-based module.

The results show that the success of the PBL experience is directly related to the degree of academic self-efficacy, peer learning and team efficacy that exists. Measures of the student perceptions within this module indicate that students strongly perceived that their team interactions led to high levels of team efficacy, peer learning and academic self-efficacy (research question 1).

Correlations among these constructs (research question 2) vary in strength with stronger associations existing between team efficacy and peer learning and between peer learning and academic self-efficacy. The low correlation between team and academic self-efficacies also suggests a relationship model where an increased team efficacy leads to improved peer learning which then gives rise to an enhanced academic self-efficacy. We however expect these relationships and their interdependence to vary from module to module given that academic self-efficacy is a function of module learning outcomes.

Academic self-efficacies for this module were also found to be bimodally distributed with approximately 35% of students rating their confidence as average to above average (50 to 75) and the rest having higher confidence levels above 75. Given that a large percentage of students (85%) felt they learnt from each other and that this collaborative experience strongly improved their understanding of mechanical design principles, this bimodal distribution could be a result of the lower confidence expressed when carrying out individual elements of the module.

Interactions throughout the module also allowed for community building in other parts of the course; students formed or intended to form informal study groups for other modules and there was an increased social interaction outside of the university for a small number of teams. These interactions were enhanced using social media (primarily WhatsApp and Facebook). Less successful experiences were however had by students who perceived their groups to have lower cohesion; these students nevertheless felt that their overall experiences with the module led to an increased academic self-efficacy.

This is significant as embedding approaches which encourage high levels of academic self-efficacy within academic programmes can meaningfully influence student motivation and progression; how a student believes they will perform academically is often as, and sometimes more, important towards sustaining academic motivation than just attaining the academic target itself.

The questionnaire used also had a high internal consistency between the constructs and their individual descriptors which indicates that it can be used to reliably examine further PBL projects. This is important as we continue our work to introduce new- and strengthen existing PBL modules within our programmes and would be particularly valuable for planning future module design within the MEng Chemical Engineering programme at ICL in which many modules are team-based.

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