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BENEFITS AND LIMITATIONS OF ADOPTING PROJECT-BASED LEARNING (PBL) IN CIVIL ENGINEERING EDUCATION – A REVIEW

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Abstract. *A lack of balance between theoretical and practical learning has been a systematic problem in engineering degree courses during the second millennium. The challenge for the third millennium therefore remains that of blending assimilation of knowledge with responsible application of theory in practice, during the formative undergraduate years. A report published at the turn of the millennium noted the serious decline in applications from bright young people to study engineering, especially built environment programmes, while drawing attention to a finding that programmes which attract the best students are those that encourage a high level of interdisciplinary thinking and project work. Inductive teaching and learning approaches include inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning and just-in-time teaching. Such constructivist methods are deemed to be student-centred, placing more responsibility on the student for their own learning as they actively construct and reconstruct their own reality, while the teacher acts as facilitator in the process. Two approaches are slowly emerging as preferred in civil engineering education: problem-based learning and project-based learning. While they share commonalities, differences exist. Problem-based learning focuses on knowledge acquisition while project-based learning (PBL) emphases the application and integration of knowledge. However, widespread acceptance of such innovative education strategies is not yet a reality and the relevance and effectiveness of both approaches in engineering education is still open to question. The body of literature on the topic continues to grow. This paper investigates recent evidence in civil engineering education and identifies trends that may be helpful in the successful reimagining of programme ethos and curricula. The study considers application context (e.g. final year capstone project, first year design project), data type (e.g. student feedback, tutor reflection), and measure of effectiveness model (e.g. qualitative/quantitative analysis). Dominant benefits and challenges are identified.*

1 INTRODUCTION

A failure to achieve balance between assimilation of knowledge and responsible application of theory in practice in engineering education has remained elusive [1]. Interest in engineering careers, and particularly those of the built environment, continues to decline as we lose young talented people to programmes offering project and interdisciplinary experiences [2]. Interestingly, such experiences are intrinsic within leaner-centred (i.e. inductive) pedagogies. Compared with traditional teacher-centred (i.e. deductive) instruction, modern cognitive science and extensive research make a case for the superiority of a learner-centred (i.e. inductive) approach to teaching [3-6]. A number of inductive teaching and learning approaches exist including inquiry learning, problem-based learning, project-based learning (PBL), case-based teaching, discovery learning and just-in-time teaching [4]. Such constructivist methods are deemed to be student-centred, placing more responsibility on the student for their own learning as they actively construct, and reconstruct their own reality, while the teacher acts as facilitator in the process [7]. A review of literature indicates that problem-based learning, and project-based learning, have emerged as the inductive teaching approaches in civil engineering education. While sharing commonalities, differences exist as problem-based learning focuses on knowledge acquisition while project-based learning (PBL) emphasises the application and integration of knowledge [4, 8]. Despite existing since the early seventies, widespread adoption of such methods is not evident [8] and reservations persist. In 2003, Mills and Treagust [9] were prompted to question the relevance and effectiveness of learner-centred approaches such as PBL. Their research considered PBL implementations within civil engineering and particularly research by Hadgraft [10-13]. The current research seeks to further examine if the question raised has been answered within published research on the application of PBL within civil engineering in the intervening period. Consequently, the research considers the 15 year period since the Mills and Treagust study [9] (i.e. 2003-2018) with dominant benefits and challenges identified.

2 APPLICATIONS OF PBL IN EDUCATION

A comprehensive literature search resulted in a total of 27 studies being identified for review as part of the current study [14-40]. A summary of key aspects of reported PBL applications within the discipline of Civil Engineering is included in Table 1 and is presented in chronological order commencing with the most recent. Aspects of the studies considered include year of study, topic of study, stage of study, data type/mode of collection (e.g. student feedback, tutor reflection), and measure of effectiveness model (e.g. qualitative/quantitative analysis). The rate of publication over the period considered is approximately three papers every two years. The maximum was five in 2015, while there were none in 2004, 2006, and 2009. In terms of publication type, 16 are peer-reviewed journal papers (i.e. 60%), nine are conference papers (33%), one symposium paper and one research article. The breakdown in terms of stage of study and topic of study are presented in Figure 1.

Table 1: Summary of PBL research in Civil Enginnering

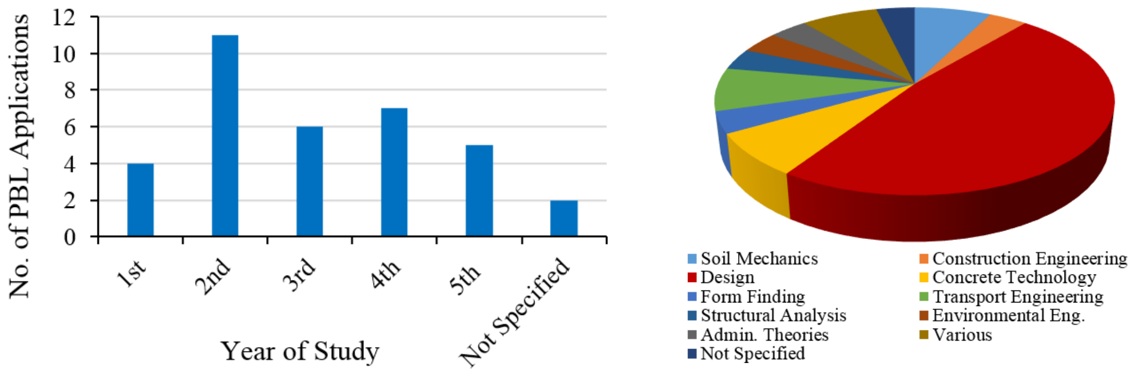
Ref.	Data Collection Mode/Data Type	Measure of Effectiveness Model	Key Findings
[14]	Student Grades; Student Questionnaire	GPA and Assessment Grades	2nd year Soil Mechanics: Similar performance for PBL and control group but PBL brings greater student engagement, especially from those with relatively lower GPA
[15]	Student Questionnaire; Student Focus Groups; Tutor Interviews	Author observations based on student and tutor feedback	Construction Engineering: Identifies for practitioners evidence-based strategies for PBL implementation, covering case studies, just-in-time, peer instruction, self-directed and cooperative learning
[16]	Student Questionnaire	Mean values of number-based Likert scale responses; Student grades	2nd year Soil Mechanics: Students and staff find collaborative model of PBL better than cooperative. Collaborative model overcomes compartmentalisation of course contents among student team members; Effectiveness of PBL increases with repetition of PBL experience; PBL is effective academically; Workload neutral for students but higher for staff; Payback for staff comes in follow-on stages with students as more autonomous learners.
[17]	Student Questionnaire; Student Grades	Mean values of number-based Likert scale responses	3rd year Design: Recommends use of active learning to allow the students to fully engage in content knowledge prior to starting interdisciplinary PBL; Use of physical scaled models to facilitate understanding of concepts; Use of hand sketching to generate ideas, communicate designs, understand complex ideas and react during interdisciplinary discussions.
[18]	Student Questionnaire	Mean values of description-based Likert scale responses	Final year Design: Workload in PBL needs to be carefully managed – in case studies, use a medium scale project.
[19]	Student Questionnaire; Student Focus Groups	Mean values of number-based Likert scale responses	2nd year Concrete Technology: PBL was well received and can facilitate deep learning; PBL projects must be designed with specific graduate attributes in mind.
[20]	Student Survey	Mean values of number-based Likert scale responses	1st year Design: Recommendation is that students be required to take on at least two roles within the team during the PBL project to stretch their skills development.
[21]	Student Pass Rate; Student Attendance; Student Questionnaire	Mean values of number-based Likert scale responses	1st year Design: PBL brings greater student engagement and is very effective if clearly linked to competences being assessed in the module – which may require reducing number of competences to be developed in the module. Staff workload is a matter of concern – PBL was conceived for small groups of 8-10 students with a tutor per group.
[22]	Student Questionnaire	Extracts from students' feedback	5th year (M.Eng.) Structural Form: [22]

Table 1 ***(continued)***: Summary of PBL research in Civil Enginnering

Ref.	Data Collection Mode/Data Type	Measure of Effectiveness Model	Key Findings
[23]	Student Questionnaire; Student Grades	Mean values of number-based Likert scale responses; Comparison of student grades	4th year Transportation Geotechnics: PBL student scores higher than control group; PBL encouraged confidence, ownership of learning and clarified connections between different parts of the programme.
[24]	Student Grades	Statistical comparison (ANOVA) of grades.	3rd / 4th year Design: Impact of PBL on learning outcomes is not consistent; Generally, it can improve results but do not assume all learning outcomes in a module are equally impacted.
[25]	Peer assessment; Student Grades	Peer assessment vs tutor's overall module grade	2nd year Design: Peer-assessment grades in PBL correlate well with final project grades – both are heavily influenced by engagement rather than ability.
[26]	Grades for 'reflection' element of assessment	Grades compared	2nd year Reflection: Reflective writing is enhanced if guidance is provided but it requires time to teach authentic reflective writing.
[27]	-	-	4th year (MEng) Design: Students responded well to mastering a new technique (Building Information Modelling) through the use of PBL, combining core skills of quantitative reasoning, critical thinking, communication skills, team-working and information technology.
[28]	Student Questionnaire	Mean values of number-based Likert scale responses; Comparison of student grades	5th year (MEng) Design: High student satisfaction rating with PBL (70%) but the time input required by students and staff needs to be co-ordinated with other modules, especially in respect of submission deadlines.
[29]	-	Researcher's reflection on PBL application	2nd year Concrete Technology: Use of PBL in laboratory exercises ensures engagement (no 'free riders') and greater connection between individual laboratory exercises and module learning outcomes.
[30]	Limited number of student feedback statements	Researcher's reflection on PBL application	2nd year Design (Water Engineering; Geotechnical Eng): Impact of change to PBL from didactic teaching greatly exceeded expectations in respect of depth and rigour of learning.
[31]	Case study	Tutor discussion of application and observations	3rd & 4th year Transportation Engineering: PBL increased student engagement but is resource hungry and peer-assessment may occasionally requires careful moderation by the module co-ordinator.

Table 1 ***(continued)***: Summary of PBL research in Civil Enginnering

Ref.	Data Collection Mode/Data Type	Measure of Effectiveness Model	Key Findings
[32]	-	-	Design: PBL recognized in promoting students' creative thinking, improving analysis and problem solving ability and promoting lifelong learning
[33]	Method not specified	General (single) concluding statement based on feedback	Final year Design: Staff time commitment is a concern in implementing PBL. Monitoring students' time management is also prudent; Team-building exercises between instructor and student may be needed to encourage open discussion.
[34]	Grades for key tasks within assessment	(a) Grade performance (b) Grade performance versus tutorial attendance	1st & 2nd year Structural Analysis: Attendance at tutorials has a significant impact on conceptual understanding.
[35]	Limited number of student feedback statements		2nd – 5th year Design: PBL complements traditional education in a very impactful positive way but requires lecturers who are both well trained from practice in engineering and are dedicated to teaching.
[36]	-	Researcher's brief reflection on PBL application	1st year Design: PBL encourages early requests for clarification of understanding gaps; Consistency in peer-assessment is problematic.
[37]	Classroom observations; Student Questionnaire	Tutor discussion of feedback and observations	5th year Administration Theories: PBL most beneficial if introduced early in the curriculum; Consideration may need to be given to increasing credits due to higher time commitment.
[38]	Student Questionnaire	Statistical comparison (ANOVA) of (a) feedback ratings and, (b) GPA	2nd year Environmental Engineering: Some evidence that PBL may assist attracting under-represented groups to engineering courses by appealing to their learning style.
[39]	-	Comparison of PBL across three institutions	1st –5th year, various topics of study: Consideration needs to be given to collateral negative impact of PBL success in further discouraging students from putting time and effort into traditional lecture attendance.
[40]	Student Grades (Overall & specific project marks); Student Questionnaires	Statistical comparison of (a) feedback ratings and, (b) Course grades	3rd year Design: Identified strong link between PBL success and the students' choice of an engineering programme due to their inherent interest in projects



(a) Stage of Study (b) Topic of Study

Figure 1: Stage and topic of study for PBL application

5 BENEFITS & CHALLENGES

5.1 Benefits

Based on student feedback, operating within a PBL approach assists in the development of graduate attributes and skills for professional practice [16, 19, 23, 24, 28, 32, 35-37]. Zeng and Xu [32] present a case study detailing various aspect of the application of problem-based learning in a civil engineering programme and highlight benefits in terms of innovation, communication, teamwork, project and time management. McCrum use PBL as a vehicle to encourage higher order critical and creative thinking in students [17], while others also concluded to such positive outcomes [27, 32, 36]. A comparison of graduates from the PBL based engineering programme at Aalborg University, and those from the traditional programme at Danish Technological University (DTU), found that Aalborg graduates were stronger in communication, team skills, ability to complete a full project, while DTU graduates were more capable of independent work but required more training [9]. In addition to such attributes, Mills and Treagust [40] conclude that students also develop competence in evaluation of alternative views, negotiation of understanding, and realise the importance of learning for understanding. Lopez-Querol *et al.* [23] concluded that the interdisciplinary aspect of PBL assists students in clarifying connections among different civil engineering disciplines. Despite limited feedback from a student survey of problem-based learning experiences, Ahern [31] noted that, in general, comments were positive with students stating that it helped them learn more about themselves.

As PBL approaches commonly used projects which are typical within an industry context, students consider the work as relevant and thus are more motivated to learn [14, 21, 28]. Increased interaction between faculty and students on a ‘one on one basis and small group informal sessions can benefit improved relationships [28]. In a study of the perceived curriculum, student feedback on their learning experience within a PBL course scored relevance and appropriateness of assessment highest as PBL enhances learning and critical thinking via working on projects in a ‘real life’ context, thereby achieving deeper learning [40]. Mills and Treagust [9] cite a study which indicates that the dropout rate in Aalborg University is 20-25% compared with a 40% dropout rate for traditional programmes in Denmark, with such a benefit also cited elsewhere [21].

5.2 Challenges

The introduction of problem-based learning can be challenging as students often dislike such an approach, finding it "*difficult and messy*" at first [14, 31, 36, 37]. When students complained of insufficient support during tutorials, Ahern [31] suggested that students' familiarity with traditional tutorial sessions, where the tutors had complete solutions to set questions, was a likely source of the students' frustration. An exploration of the combined use of traditional and project-based learning approaches gives credence to such opinion, as results revealed low motivation to embrace new pedagogies such as PBL among the majority of students, who instead preferred traditional methods as "*they know what to expect from it*" Initial reaction of students can be one of suspicion and rejection, however, this was overcome as students realised the positive effects on their preparation for future professional life [16, 37].

Engineering topics, including mathematics and physics for example, have a hierarchical knowledge structure meaning that missing a topic within a sequence can affect the ability to understand and learn in subsequent stages, thereby impacting programme wide implementation of PBL [9, 40].

A perception exists that PBL will involve a significant workload on the part of the individual student [9, 14, 16, 18, 19, 28, 30, 37]. In a case where students had the option of choosing between a project-based learning type assignment and a traditional assignment, student feedback indicated that they were reluctant to invest the additional time they felt would be required for a project-based assignment, indicating that the project-based learning type assignment required almost double the time [14]. In a study of 99 students undertaking a final year design course which implemented PBL, Kwan [18] reported that 56.5% of students indicated that the workload was excessive, with 69% spending 11 hours or more on the required project work. The issue of time is exacerbated when problem-based learning is partially implemented within a programme and requires ongoing management to limit potential adverse effects on other modules [30].

From a teaching perspective, while some view the implementation of PBL as little more than rethinking and reorganising of previously used content and timetabling, setting and grading of project work can prove extremely time demanding [14, 21, 22, 28, 32, 33, 37, 40]. Pinho-Lopes and Macedo [16] echo such concerns in terms of instructor workload but acknowledge that such approaches benefit students in the long run, better preparing them form more autonomous work, particularly at Master level. While enjoying the experience, Aparicio and Ruiz-Teran [35] highlight the additional effort required when compared with traditional methods, citing preparation of "ad hoc" materials for the diverse range of student projects and the significant assessment workload as examples. The issue of class size is also an issue as PBL typically suits smaller class sizes [21]. Challenges are also experiences in terms of resources such as teaching staff [31], technical support [29, 38], appropriate physical spaces to accommodate PBL activities [22, 39], and materials [22, 38].

Assessment methods require careful consideration, in particular the approach to grading of group work where there is disparity in the contributions of individuals [9]. It is important that instructors optimise the complexity of projects to address student workload concerns [15, 18, 24, 28] and enhance deep learning [19]. Shekhar and Borrego [15] highlight the importance of instructors optimising the complexity of projects to address student workload concerns, with feedback from students playing a key role, a sentiment echoed in other studies [18, 21, 38].

7 CONCLUSIONS

The majority of reported cases relate to application of PBL within individual courses as oppose to across programmes. Conclusions within the literature convey significant benefits in the adoption of PBL as a pedagogical strategy within civil engineering education. Consistently reported benefits include improved graduate attributes such as communication, teamwork, project management and time management. In addition, PBL is typically based on 'real' projects, thereby ensuring relevance and increased motivation. However, the prominent challenge for both learners and tutors is the increased time required to address the requisite workload.

In 2003, Mills and Treagust [40] noted that PBL was generally implemented by individual lecturers within courses and that evaluation of its effectiveness was limited to qualitative statements from student surveys undertaken upon completion of the course, thereby prompting the desire for a more rigorous evaluation within a framework from education theory. Based on the current research, the body of evidence demonstrating the effectiveness of PBL in civil engineering continues to be qualitative in nature. As with Mills and Treagust in 2003, the search for more rigorous and quantitative evaluation continues.

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