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Exploring Project Based and Problem Based Learning in Environmental Building Education by Integrating Critical Thinking*

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Project Based and Problem Based Learning (PBL) has been widely utilised in engineering higher education. One of the many benefits from this innovative approach is enhanced critical thinking of students. However, there appears to be scope for developing how critical thinking can be integrated into PBL, to promote deep learning in a complex multi-disciplinary environment. This paper addresses this knowledge gap by presenting research in exploring PBL using an integrated critical thinking process model. The study was carried out on a cross-module multi-disciplinary group building design project, undertaken by second-year undergraduate students registered to the Environmental Building programme at University of Plymouth, UK. Although the students perceived critical thinking to be important to their projects, surface learning dominated the PBL process, particularly at the early stages of the project. To realise the full benefits from PBL, staff involved suggested that proper mechanisms should be provided to enable deeper learning. This requires the philosophy of critical thinking to be embedded in the design and implementation of the curricula, before and during the project. The process model of critical thinking developed provides such a mechanism, to help students create, develop, justify, implement and evaluate building design solutions. The mapped process of the design project provides a worked example of integrating critical thinking into PBL in Environmental Building education, which should contribute to future debate on PBL in the wider higher education community.

Keywords: critical thinking; environmental building; project based and problem based learning; student learning

1. INTRODUCTION

THE ATTRACTION of Project Based and Problem Based Learning (PBL), under its many guises, has led to an increase in its use [1]. Despite the debate on the distinction between Project Based and Problem Based Learning, many PBL studies were carried out using a project and, as de Graaff and Kolmos [1] suggested, project work is problem-based by definition. Therefore, PBL is used in this paper to refer to Problem Based Learning carried out in project context as a meaningful way to learn skills and knowledge.

The increase in PBL across the curricula is understandable, given the claims that have been made regarding positive outcomes for enhancing student learning. One such claim is that a PBL approach 'develops a range of skills, including problem-solving, group working, critical analysis and communication' [2]. Since the early developments of PBL, much research and literature has been devoted to assessing and analysing the different characteristics of PBL programmes. However, Savin-Badin [3] pointed out that PBL driven research needs to focus on, and examine in greater detail, the key skills and themes that are widely attributed to PBL, and how these interact with the complexities of teaching and learning. One of these skills is critical thinking. The concept of critical thinking has been widely reviewed in the higher education context. Cottrell [4] defined critical thinking as a complex process of deliberation which involves a wide range of skills and attitudes. Bowell and Kemp [5] regarded it as a tool for argument analysis, and thinking clearly and rationally. As such it is seen as yet another desirable key skill for graduates to demonstrate, some even argue that, in today's workplace, critical thinking abilities are needed now more than ever before [6]. However, these descriptions offer an oversimplified explanation. Critical thinking is more than just a skill or a tool, if it is to be a desirable attribute for graduates to take into their

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professional careers, then it is as much about attitude and disposition [7]. Hilsdon et al. [8] developed a critical thinking model which is underpinned by a 'functional-narrative' approach, with its structure based upon description, analysis and evaluation, in order to 'deconstruct and reconstruct a given problem, topic or knowledge claim' [7]. Drawing on the model developed by Hilsdon et al. [8] and the features of PBL, this paper defines critical thinking as a questioning approach to creating, developing, justifying, implementing and evaluating suitable solutions in order to address a project or problem with an ultimate purpose to help students determine their own learning directions and thus enable deeper learning.

Although PBL has been studied in higher education disciplines such as medical health [9], architecture [10, 11], and civil engineering [12], little research has been carried out in relation to Environmental Building, which is an area attracting increasing interest in teaching and learning [13]. Given the increasing awareness of environmental issues and the global sustainability agenda, the approach of improving criticality in Environmental Building PBL will also enhance student employability and engagement with practice.

This paper reports on an exploratory study which investigated the integration of a critical thinking approach to PBL and its impact on student learning. The study was carried out within the context of a cross-module, multi-disciplinary building design project, undertaken by undergraduate students registered to the Environmental Building programme at University of Plymouth, UK. The paper aims to improve the effectiveness of PBL in Environmental Building disciplines by integrating critical thinking. It investigates the interactions between PBL and critical thinking processes, explores the students' perspectives, knowledge and skills, and examines the perceptions of relevant staff on the effectiveness of utilising the critical thinking approach in PBL. The results lead to the discussion on how PBL in Environmental Building education can be embraced by an earlier and more structured integration of the critical approach.

2. THE CONCEPT AND UTILISATION OF PBL

PBL has been widely recognised as an effective pedagogical process, in a range of higher education disciplines. The variable characteristics and potential benefits of applying PBL have been reported. Generally, students are believed to improve in two significant areas: depth of knowledge and knowledge retention. This means gaining an overall deeper understanding of their subject area and retaining the knowledge gained for a longer time period [2]. Previous research also suggested that there are more specific key skills that undergo improvement, such as motivation, explorative learning, self-directed learning, communication, and management skills. Cirstea [14] and van Kampen et al. [15] experienced an increase in attendance and overall mark when PBL was integrated into their degree programmes, in Electronics and Physics respectively. Douvlou [16] found that students' evaluation of PBL, utilised in Sustainable Design and Building Management, indicated that they welcomed the opportunity to express more of their own opinions, develop ideas, interact more with both peers and tutors, and learn for themselves. Furthermore, increased critical thinking, teamwork and problem solving skills were found to be products of PBL when applied to a Public Speaking course by Sellnow and Ahlfeldt [17]. The development of good communication and management skills, including decision-making, creativity, flexibility and adaptability, was also experienced by engineering students [18].

Therefore, the overall evidence points to a number of potential advantages regarding the combined effects of PBL, which was further enhanced by Dochy, et al. [19] whose review of 43 articles on PBL identified very little in the way of negative effects. This range of advantages of PBL to students, staff and employers makes it attractive to universities, if they are to increasingly engage with the graduate employability agenda, to produce competent 'work ready' graduates for the fluctuating world of employment [20]. The nature of PBL lends itself well to this aim, by exposing students to real world applications and preparing them to be successful in industry [17, 18].

However, despite the many claimed benefits from PBL, some recent research revealed that disadvantages of PBL also exist. Hung et al. [18] reported that some students felt PBL was more time-consuming than a conventional course. Douvlou [16] also revealed that students could feel unguided or unclear about their learning objectives and how they would be assessed, and that the group-working aspect of PBL was seen by some students as a disadvantage. Furthermore, Dochy et al. [19] warned that the knowledge base acquired by students applying PBL might not be as extensive when compared to students taught in more conventional learning environments. There remains an element of caution among those with an extensive background in PBL, regarding the motives behind its implementation and how it interacts with other teaching and learning methods, and that the full potential of PBL will only be realised when all these issues have been explored thoroughly [3]. All these concerns indicate that further research in PBL is required.

3. METHODOLOGY

This study was action research in nature. It was embedded with a purpose for 'improving practice' [21] and the reflective practice circle in the process of 'Plan-Do-Check-Act' [22]. The study was carried out within the context of a large and complex building design project at University of Plymouth. Sixty-six second-year undergraduate students from the Environmental Building programme participated in the project. The design for implementing PBL in this programme took into consideration a number of features of the project, some of which could be seen as distinctly advantageous to the use of PBL and student learning. The relevant features of the project were identified as cross-module, cross-discipline and cross-role, with a real-world project utilised for PBL.

3.1 Cross-module, cross-discipline and cross-role

Three modules were involved in the design project, ENBS243 'Technology of Large and Innovative Buildings', ENBS246 'Construction Management Processes and Principles', and ENBS245 'Building Surveying Principles and Practice'. The 66 students were from four different, but inter-related, courses, i.e. architecture, building surveying, construction management, and environmental construction surveying. The students worked in small groups, each group being required to cover at least five roles throughout the project from the following: architect, structural engineer, construction manager, building surveyor, environmental surveyor, building services engineer, estimator and buyer. This approach covered the main disciplines involved in a building design and management project, and reflected the complex and collaborative nature of construction. The features of 'cross-module, cross-discipline and cross-role' provided individual students with the opportunity to occupy a role that was closely associated to their own programme. That enabled them to utilise and develop further their own specialist knowledge base, but also to experience and appreciate 'others' work' in a large interdisciplinary project context. The design of these three features addressed the concerns of Fruchter and Lewis [23] that if architecture, engineering and construction students are not exposed to this cross-module, interdepartmental experience, it can hamper their overall effectiveness of functioning in an interdisciplinary team when they come to enter industry. This approach ensured that a multidisciplinary learning environment was provided.

3.2 The project and assessments

The students were asked to design a new building for the Faculty of Technology at the University, on the site of the current Brunel Laboratories. This building should provide laboratory, teaching, research, and administration areas as specified. The building should also become an architectural landmark, fitting in well within the contemporary 'urbanistic' campus and city centre. Furthermore, the design should be recognised as a flagship building of the University that boasts state-of-the-art technologies and facilities with sustainability, flexibility and wellbeing credentials. Detailed specifications and requirements were outlined in the design brief which was provided to the students at the outset of the project.

The PBL project was designed as a continuous process of design development, feedback and improvement, leading towards the final project presentations and exhibition. An interim assessment was undertaken six weeks into the project. The final assessment consisted of two parts, an assessment by a panel, including academic staff and industry experts, and a peer assessment of student group members. While the first part of the final assessment was focused on the design solution, and the skills and knowledge demonstrated by the student groups in their presentations, the second part was an examination of student learning and contributions perceived by their fellows.

3.3 Data collection and analysis

The data used for this paper was collected through the assessments of student design projects, group interviews with students regarding their perceptions on PBL and critical thinking, personal discussions with the academic staff involved in the project, and observations throughout the PBL process. Assessments of both the student interim and final presentations were considered, which provided a comparison of criticality evidenced in the students' work between the early and final stages of the PBL. This comparison, coupled with the interviews with students, discussions with staff and observations undertaken by the researchers, provided a reasonably clear picture of the trajectory of student learning performance throughout the design project. Student feedback on the use of critical thinking in PBL was also collected as part of the design project feedback questionnaire survey, undertaken at the end of the final presentation of the project. In all, 66 students, 9 members of academic staff, 3 members of learning support staff and 12 external assessors were involved in the data collection at different stages of the PBL learning process. The data was largely qualitative in nature, and was analysed using the content analysis method [24].

4. RESULTS AND DISCUSSION

4.1 Process of integrating critical thinking into PBL

A critical thinking approach was integrated throughout the PBL process and evidence of its utilisation was required for the design project. The process of critical thinking used in this paper is illustrated using a process model (Fig. 1). The process represents five main stages of achieving and optimising solutions for a project, a problem, or a component of the project/problem, which include creation, development, justification, implementation and evaluation. Each stage is associated with several provoking questions. The stages and the questions, together, provide the student with a

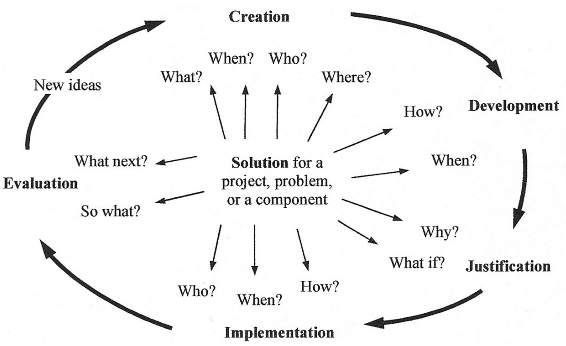

Fig. 1. Process model of critical thinking.

structured approach to critiquing and optimising their building design solutions. From that process, the students acquire and create knowledge and skills. To some extent, this critical thinking process reflects Kolb's [25] experiential learning model which emphasises the critical aspect of the learning process as the transformation of experience in both objective and subjective forms.

The paper presents a research attempt to integrate such a critical thinking process into PBL in Environmental Building education. Feedback from both learners and staff suggested that the integrated process improved the effectiveness of utilising PBL in Environmental Building learning, and encouraged deeper learning by the students in a multi-disciplinary project working environment.

Throughout the various stages of the PBL process, the importance of critical thinking was emphasised and its use was encouraged (Fig. 2). The design project brief highlighted the necessity of utilising a critical approach for developing not only the overall solution, but also detailed components of the design, e.g. construction technology selection for the building design. The application of the critical thinking process in the PBL process is explained in line with the stages as follows. Firstly, a lecture was provided to the students on critical thinking by the University's Learning Development Service at the outset of the design project, immediately after the project briefing and mobilisation. The theory and utilisation of critical thinking were explained within the subject specific context of appraising construction technology and building design. Relevant supporting documents were uploaded to the Student 'Portal' (an intranet) for additional reading and self-directed learning. A follow-up tutorial session was then provided, as part of a student group design workshop, to further enhance student understanding of critical thinking and its utilisation in PBL in the design project. During the initial student design workshops and their interim presentations, the students were encouraged to justify their design ideas and development decisions. They were also required to evaluate their design solution consistently in order to ensure the design brief was addressed and best value was delivered to the 'client', the University. Colleagues from Learning Development Service participated in all the advisory workshops, which, joined by the academic staff for the project, provided the students with consultations on the methodology of critiquing, justifying and evaluating design decisions. A review of the use of critical thinking was integrated into the session of a final review and mobilisation for the project presentation and exhibition. For the final assessment, both academic and industry assessors were briefed on

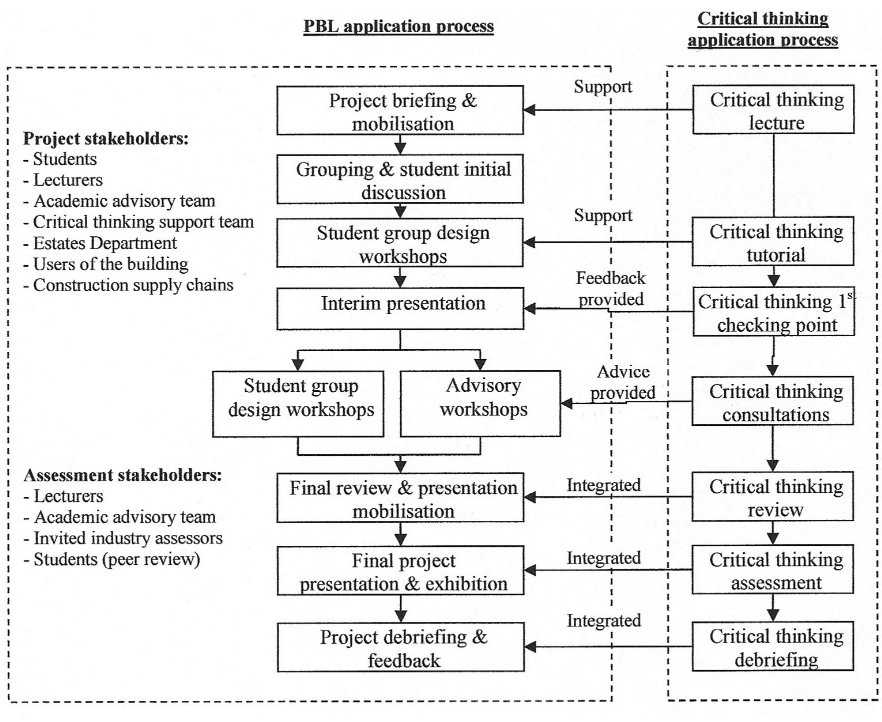

Fig. 2. Mapped process of PBL with critical thinking integrated.

the requirement for students to utilise critical thinking in justifying their design solutions. Finally, during the project debriefing at the end of the final presentation and exhibition, an overall evaluation of the criticality of student design projects and their use of the critical thinking approach were also provided (Fig. 2). The students were encouraged to reflect on their learning and continue utilising the critical approach for their further study.

4.2 Impacts on student learning

The interim assessment of student design projects suggested a paucity of understanding of the application of critical thinking. Although the critical approach was explained and its use for producing the design solution were demonstrated in the lecture and follow-up tutorials, sporadic evidence was found of critical analysis and evaluation of design alternatives in the students' initial work. Interviews with students and staff suggested that the short time available during the interim presentations, 15 minutes for the presentation and 10 minutes for discussion, gave little time for students to demonstrate their critical decisions made up to that point. The students focused the interim assessment on evidencing the current status of their design solutions and gaining feedback, rather than demonstrating how they achieved their interim progress and any critical decisions they made during that process.

In line with the lack of knowledge and aptitude of critical thinking demonstrated in the students' work during the early stages of the PBL process, their level of satisfaction and sense of achievement with their learning and overall performance in the design project was also observed to be low. However, when a critical approach was understood and adopted at the later stages of the PBL process, particularly through the advisory workshop sessions, most students claimed that they would be able to apply this to a multitude of circumstances and disciplines, and some considered it as a 'threshold concept'. Consequently, students' satisfaction and sense of achievement with their learning appeared higher than that in the previous stages.

The student feedback provided at the end of the project on the integration of critical thinking into their design project was generally positive. Most acknowledged the benefits from applying the critical thinking process for developing, justifying and evaluating their design solutions. However, some students commented that the approach should have been introduced earlier and the link between the use of critical thinking and project assessments should have been made more tangible. Examples of good practice of applying critical thinking in building design decision-making was also recommended by some students for future project learning.

Students felt that the integration of critical thinking encouraged them to ask meaningful exploratory questions (Fig. 1) at the key stages of PBL (Fig. 2). This helped them achieve an improved understanding of the design brief and make better justified building technology choices in their final presentations than those demonstrated in the interim assessment. This feature suggested that the students were moving towards obtaining a greater breadth of knowledge while reaching the deeper level of learning through PBL with critical thinking integrated. This finding provides empirical evidence which addresses the concerns of de Graaff and Kolmos [1] that PBL pedagogy for engineering education should ensure the attainment of both depth and breadth of learning.

4.3 Learning from the PBL process

Results from the group interviews with the students, and discussions with the academic staff involved in the project, suggested a range of underlying reasons for the lack of in-depth analysis of the design projects, particularly in the early PBL stages. Firstly, the students struggled to understand and implement the process model of critical thinking, and therefore did not really embrace the critical approach in their thinking.

Secondly, there was a lack of appreciation of the relationship between PBL, critical thinking and the design decision-making process. The unclear requirement for critical thinking in the project briefing document contributed to students' lack of appreciation of the importance of the approach. Thirdly, many students appeared to have an insufficient level of understanding of the methods for critiquing, justifying and evaluating design decisions. These reasons could be attributed to the timing of introducing the critical thinking model, which might have been better placed before the start of the project. An earlier introduction of the model would have given the students the opportunity to become familiar with the approach and its utilisation, before having to incorporate it into a large and complex design project. This result suggests that a strategy for improving the effectiveness of PBL would be to embed critical thinking into the programme from an earlier stage. Also, the process suggests that it is beneficial to utilise the materials and knowledge of learning support service in order to embed content and improve student learning, activities which are normally considered to take place between students and lecturers only.

The importance of the roles of the academic team in running a successful PBL programme and integrating the critical approach cannot be underestimated. During the PBL process, the academic team took the roles of facilitating and supporting, which is acknowledged in many PBL studies. However, during some advisory workshop sessions, it was difficult to distinguish these roles from more conventional teaching as the staff provided a significant amount of information on both discipline and critical thinking. This was probably attributed to the nature of the learner cohort, as second-year undergraduate students, and the fact that the critical thinking model was formally integrated into the PBL in the programme at the University for the first time. Several members of academic staff questioned the applicability of a design project of this magnitude for second-year undergraduate learning. Instead, they suggested that students would benefit more from this design project if it was undertaken in their final year. They argued that students, in their final year, would have a more comprehensive knowledge base and skills to carry out the design project and adopt a critical approach more effectively. For example, a senior academic explained that students, in final year, would have studied many other modules and therefore would have achieved a more comprehensive knowledge base of building design and technology decision-making. They would have also interpreted the critical thinking process in a project context more effectively. Another academic added that final-year students would also have greater aspirations to critique design solutions and think more from the practical perspective in order to gain a smooth transfer to practice after graduation. These suggestions echo the claim by Cawley [26] that PBL tends to be introduced in the final year of higher education. However, there exists research which demonstrates the effective use of PBL in first year courses [27]. The key, therefore, to ensuring the effectiveness of using PBL, despite the student stage or level, is that such an approach must be adapted to suit disciplines and knowledge base [3]. In addition, the project or problem selected must be considered carefully, whilst it is beneficial to expose students to a 'real' problem scenario [16], it must be in line with and reflect realistic learning outcomes, which can be one of the greatest challenges of implementing PBL [11]. The integration of critical thinking into the PBL process for Environmental Building education presented in this paper offers an initial worked example that can be built upon for future adaptation. However, the real-world problem scenario, and 'cross-module, cross-discipline and cross-role' features of the project were appreciated by the students, and recognised as effective ways to generate interest, promote motivation and help develop 'soft' skills. Apparently, these features and benefits achieved are consistent with the findings of previous research [1, 23].

5. CONCLUSIONS

This paper has presented research in exploring the use of PBL in Environmental Building education by integrating a critical thinking approach. The integrated methodology was considered beneficial for enhancing some of the recognised benefits from utilising PBL, in terms of enabling deep learning in complex multi-disciplinary project working environments. The paper identified the lack of an explicit link between the use of critical thinking, PBL and the design project in Environment Building education. The model of critical thinking and the process of PBL presented in this paper should help address this knowledge gap. The critical approach should be applied for creating, developing, justifying, implementing and evaluating design solutions for the project. Surface learning was evident in the student design project, particularly during the early stages of the project. In order to realise the full benefits from the PBL process, proper mechanisms should be provided to enable student deep learning. This requires the philosophy of critical thinking to be embedded in the design and implementation of curricula from an early stage. The involvement of, and input from, learning support service in this study provided a worked example for engaging external learning stakeholders for improvement. Despite the overall success of applying critical thinking for the second-year undergraduate design project, the effectiveness of the integration of the approach into PBL can be further improved. Similar studies of first-year or final-year projects can help extend the methodological understanding of critical thinking and PBL pedagogy. Comparative studies of applying PBL and critical thinking to other areas of engineering education can also be undertaken which should contribute to debate on PBL research in the wider higher education community.

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