Problem-Based Learning for Undergraduate Civil Engineering Education in South Africa-a Methodological Approach

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1 Introduction

Competence and skill are the two important requirements for the world of work, particularly in the engineering field in the contemporary industrial world. The onus of creating competent and skilled engineering graduates lies with the universities. The undergraduate engineering education in South Africa specifically in the Universities of Technologies (UoT) traditionally follow Outcomes-Based Education (OBE). Work Integrated Learning (WIL) forms an integral part of the curriculum. WIL is found to be not any more indispensable although work-based learning in some form is encouraged among the students by the universities. The reasons for such encouragement for incorporating work-based learning is to make the students acquainted with the real-life projects and practical problem solving, which they are likely to face in the world of work after graduating. Work-based learning essentially includes learning based on real-life projects, industrial problems, etc., which could be conducted by the students at the universities but not necessarily vising the workplaces. However, the absence of WIL and non-compulsion for the adoption of work-based learning as well as lack of internship or training after graduation at workplaces put the students at risk while facing the real world of work. Furthermore, the professional bodies and universities have made it mandatory for the students to attain competency in the exit level outcomes (Graduate attributes) before being eligible to graduate and more importantly to become eligible for candidacy for professional registration. Consequently, arguments have emerged that Problem Based Learning (PBL) in engineering education could offer one of the avenues to attain competency or proficiency in certain

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graduate attributes such as problem-solving, designing, working in groups and multidisciplinary environment, etc., and become industry-relevant. In this context, some of the UoTs have initiated efforts to introduce PBL in engineering education at large and a number of PBL workshops and learning programmes were conducted. However, PBL is not practised in engineering education let alone in civil engineering specifically in South Africa and lacks a proper methodology or processes so that it can be effectively offered to the students. There were in fact contestations of the modalities of the offerings.

Therefore, this study examined how PBL can be effectively practised and offered in undergraduate civil engineering education in the universities of South Africa. In other words, the study explored a process or methodology that can be adopted in undergraduate civil engineering so that students can be engaged in deep and active learning and attain competency. For this purpose, the study was contextualised within the undergraduate civil engineering program of a University of Technology in South Africa, which practised the OBE system. The study is premised upon the action learning approach and lessons learned from a number of workshops conducted for civil engineering students at an UoT in South Africa followed by a perception survey conducted among the students. It is argued that five sequential stages involving sequential steps in each stage can enable the effective and successful implementation of the PBL and assist the students to achieve desired learning outcomes and competency.

2 PBL: Requirements, Effectiveness and Process- Lessons from Literature

PBL as a pedagogical approach offer opportunities for active learning through engagements with meaningful problems [5]. In other words, it is a kind of curricular design and pedagogical method, which make students learn by using real-life problems [16]. In PBL, students are offered the opportunities to learn through problems solving in a collaborative setting, create mental models for learning, and form self-directed learning habits through practice and reflection, [3, 5, 16].

The underpinning philosophy of PBL is that learning can be considered a "constructive, self-directed, collaborative and contextual" activity [4]. According to scholars such as [2, 8], the principle of constructivism positions students as active learners or knowledge seekers. Also, they become the co-creators of the knowledge through new and relevant experiences premised upon prior knowledge [2, 8]. Under this principle, the students play an active role in knowledge acquisition and learn by doing. The teachers play the role of the facilitator.

Furthermore, PBL as a pedagogical strategy is appealing to many educators as it offers an instructional framework, which supports active and group learning, which is in fact premised on the belief that effective learning takes place when students both construct and co-construct ideas through social interactions and self-directed learning [5, 7, 11]. This viewpoint is further reinforced by social theories of learning which postulate the merits of social interaction in cognitive development [17].

The other advantage of PBL is that it is flexible enough to make the students learn according to the context and environment [10]. The learning can also be outcomes and attainment of competency oriented [9, 15, 18].

However, the implementation of PBL may vary according to programmes and institutions. PBL is more or less established in certain fields of study such as medicine and nursing and incorporated in physical sciences such as Physics (Servant-Miklos 2018). According to some scholars, although the methodology or process of PBL varies with programmes and institutions, yet, it follows an iterative process constituting problem analysis phase, the period of self-directed learning and, a reporting phase [1, 5, 14, 16]. The facilitator acts as a guide and scaffold students' learning, particularly in the problem analysis and reporting components. Also, the facilitator assists the students in their inquiry paths so that they can make sense of their ideas through discussion and sharing [5]. However, in general, two models of PBL have been adopted such as Barrows and Myers Model and Fogarty Model. According to as Barrows and Myers Model, there are five steps which include (1) introduction of the PBL concept and formation of the classroom environment, (2) introduction of problem configuration and assignment of duties, (3) analysis of collected information critically, (4) generation of solution(s) for the problem, and (5) abstraction of obtained knowledge and self-evaluation and reflection [12, 13]. The Fogarty model constitutes seven major steps such as (1) facing a problem: assigning a poorly structured problem to students, (2) defining the problem: restating the problem in their own words, (3) making assumptions: establishing background theories and necessary assumptions, (4) searching: searching and collecting information, (5) modifying: updating the initial problem statements based on the collected information, (6) finding alternative solutions: creating ideas for alternative solutions through communications, and (7) evaluating: evaluating a proposed solution to the problem [6, 12]. These models have been applied to different fields of study. However, since PBL was hardly practised in engineering education until recent years, there is scarcely any process or methodology established to implement it. It is also unsure if such models in their original form can be applicable to civil engineering education. Therefore, this study entails exploring to develop a methodological approach that can be suitable for civil engineering.

3 Research Methods

The study followed an action learning research framework that includes various steps such as planning, implementation and reflection to realise the end goal of exploring a method or process that can be suitably applied for PBL in civil engineering education. Action learning is considered as a process and a powerful program in which a small group of people make efforts to solve real problems and also focussed on what they are learning and how their learning can benefit each group member and the organisation as a whole based on this premise, it was found that the action learning framework is more relevant for this study. Also, this approach was found suitable in the context because PBL was implemented through a series of workshops and lessons were drawn at every stage of the process adopted from each workshop and adjustments and amendments were made to improve the process in the subsequent workshops. While doing so, a five-step action learning process was implemented that include pre-planning, planning, preparation, implementation and reflection.

Pre-planning: During this stage, discussions on the conduct of PBL was made with relevant stakeholders such as academic leaders, coordinators, instructors, industry partners, PBL experts, etc., and decisions on several accounts were made. The aspects that included in the discussions were: the student group to be enrolled, the number of students, identification of number and type of facilitators, identification of technical and industry experts, probable schedule, time and duration of the PBL, modes of delivery, broad problem types to be used in the PBL, need for intellectual and financial resources, prior knowledge, etc.

Planning: A detailed road maps for the conduct of the workshops were developed. This includes the stages to be followed, estimation of the human, intellectual and instructional resources needed, stakeholders, to be engaged, budgeting, venue, etc.

Preparation: In this stage, the student group, and facilitators were finalised. The venue, schedule and duration were decided. Students and facilitators and other intellectuals' resources such as technical and industry experts were selected and contacted for their participation was confirmed. The types of broad problems to be provided to the learners were prepared. The modalities of delivery of PBL were finalised. All instructional and intellectual resources were put in place. Moreover, students grouping were made and students were intimated of the groups they belong to and the broad problem they are required to work on so that they would be prepared with the requirement of prior knowledge.

Implementation: On the scheduled dates the PBL workshops were conducted. Before the workshops were conducted, first an induction programme was made and the students and facilitators (instructors) were given an orientation regarding the programme, the expected outcomes, the roles and responsibilities of different stakeholders including the facilitators, experts and students. Then the assessment method was also informed to both the students and facilitators. Followed by students were asked to get together group-wise and brainstorm about the various problems they would like to solve based on the broad problems before the day of the actual workshop. Sequential processes with improvements and adjustments in subsequent workshops were followed to conduct the PBL and formative assessment during and at the end of the workshops were conducted.

Reflection: After and during workshops, daily journals of various accounts were written based on the briefing and debriefing of the facilitators. Also, perceptions and students' opinions were collected through informal discussions during and after the workshops. Opinions of the various stakeholders such as industry experts, participating and academic leaders were also collected through interviews at the end of each workshop. Based on the various perceptions and outcomes of the workshops, critical reflections on the strengths, weaknesses, challenges, and further improvements were made.

The learnings from each workshop and the process followed (from the pre-preparation stage until implementation) were compiled in a journal form. Also, lessons learned were reviewed, validated and used to improve the process in the next workshop.

Also, a perception survey among the undergraduate civil engineering students who participated in the PBL was conducted. Out of the more than 70 students who participated in different PBL programmes including workshops, 42 students participated in the perception survey. The perceptions were collected by using a five-point Likert scale ranging between 1 and 5 in which 1 indicates not important, 2 indicates marginally important, 3 indicates fairly important, 4 indicates significantly important and 5 indicates most important. Moreover, non-structured qualitative discussions among 12 facilitators were also conducted.

The quantitative data collected from the perception survey was evaluated by using perception index (PI) developed based on the responses provided on the Likert scale used for the purpose by respondents of the survey. The mean of all the Likert indices is considered as the PI. Further, z tests were conducted to verify the veracity of the responses and to establish the significance of the responses. The qualitative information collected through discussions, journals and opinions were analysed by using interpretative and narrative analysis.

Further, the perceptions of the respondents were compared and used in conjunction with the various lessons learned and reflections made and opinions of the instructors and technical experts.

4 Results and Findings

Development of an appropriate methodology to deliver PBL for undergraduate civil engineering followed an iterative method of learning the lessons from each workshop. Based on the iterative process a five sequential step of PBL processes or methodology was developed, which is argued to successfully assist in effective and productive implementation of the PBL, attainment of learning outcomes and attainment of competency.

Stage 1: The pre PBL offering preparation

The first stage is the pre PBL offering preparation, which includes contextualising PBL within the OBE, a reflection of prerequisite knowledge and skill of the students, selection of stakeholders (challenge (problem owners) and technical partners) and selection of problems in alignment with learning outcomes. As evidenced by the perception survey (Table 1), the respondents perceive that this stage is fairly important. For example, respondents perceive contextualising PBL within the OBE (PI = 3.9), the reflection of prerequisite knowledge and skill of the students (PI = 3.74), selection of stakeholders (problem owners and technical partners) (PI = 3.55) are

Table 1 Perception index and the level of importance of various steps in the PBL process

Steps in PBL	N	PI	SD	Z score	Z probability	Level of importance
State 1: Pre PBL-offering preparation						
Contextualising PBL within the OBE	38	3.90	0.49	1.84	0.967	Fairly important
Reflection of prerequisite knowledge and skill of the students	41	3.74	0.53	1.32	0.906	Fairly important
Selection of stakeholders (challenge (problem owners) and technical partners)	39	3.55	0.43	1.0	0.841	Fairly important
Selection of problems in alignment with learning outcomes	41	4.15	0.65	1.77	0.961	Significantly important
Stage 2: Team building and Problem formulation and design brief						
Formation and preparation of heterogenous teams to work on a complex problem	41	4.12	0.62	1.81	0.964	Significantly important
Engagement among the team members	40	3.96	0.56	1.71	0.956	Fairly important
Identification sub-problems	42	4.35	0.42	3.21	0.999	Significantly important
Preparation of design brief	42	4.32	0.46	2.87	0.997	Significantly important
Stage 3: Stakeholders engagement and Finalisation of the design brief						
Engagement among the members across the teams	39	3.45	0.51	0.88	0.810	Fairly important
Refinement of design brief and presentation of the design brief	37	4.20	0.57	2.11	0.982	Significantly important
Engagement with stakeholders	38	3.59	0.48	1.23	0.890	Fairly important
Finalisation of the design brief	40	4.31	0.54	2.43	0.992	Significantly important
Stage 4: Idea generation and solutions						
Generation of ideas and engineering concepts	41	4.16	0.57	2.04	0.979	Significantly important

(continued)

Table 1 (continued)

Steps in PBL	N	PI	SD	Z score	Z probability	Level of importance
Engagement with technical experts	38	3.72	0.52	1.38	0.916	Fairly important
Transformation of concepts to alternate solutions (design or products)	41	4.24	0.59	2.10	0.982	Significantly important
Evaluation of the alternate solutions	39	4.03	0.49	2.10	0.982	Significantly important
Stage 5: Final design/development of product and showcasing						
Design of sustainable engineering solutions or the creation of sustainable products	40	4.25	0.62	2.02	0.978	Significantly important
Showcasing the design or product for evaluation	42	4.21	0.58	2.09	0.981	Significantly important

fairly important. However, the selection of problems in alignment with learning outcomes (PI = 4.15) is perceived to be significantly important for PBL. In this context, two of the instructors opine that:

> "…we think that prior knowledge and contextualisation of the problem are definitely important but the alignment of the problem to the learning outcomes of module or learning programme will help students to learn appropriate cognitive attributes such as analysis and design and achieve competency in exit level outcomes such as problem-solving".

Stage 2: Team building and Problem formulation and design brief

The second stage consists of the formation and preparation of heterogenous teams to work on a complex problem, engagement among the team members, identification of sub-problems, and preparation of a design brief. PBL occurs in teams and therefore the creation of appropriate teams and team building is highly essential as evidenced from the perception survey (PI = 4.12). In order to build the team and understand the strengths, weaknesses and challenges, engagement among the team members is significantly important (PI = 4.12). However, as perceived by the respondents, the highly important activities are the identification of sub-problems (PI = 4.35) and preparation of design brief (PI = 4.32). Identification of the sub-problem from the broad and complex problem makes the students narrow down and focus and work on a particular issue. Similarly, the preparation of a design brief provides the students with an outline or framework to work on the problem. It also offers them to realise the intellectual resources, time, and limitations they have. These notions are corroborated by three of the instructors and one industry expert. According to them:

"‥ the subproblem delimits the scope and focus of the work at hand. The students can know what they have to do."

"...The preparation of draft design briefs provides a kind of rough outline, objectives to be achieved and methodology to be followed. It also helps to understand the resources, limitations and constraints."

Stage 3: Stakeholders engagement and Finalisation of the design brief

Engagement among the members across the teams, refinement of the design brief, presentation of the design brief, engagement with stakeholders and finalisation of the design brief are the steps that constitute the third stage of the learning. According to the perceptions of the respondents, engagement among the members across the teams (PI = 3.45) and engagement with stakeholders (PI = 3.59) are fairly important. Engagement among the members across the teams offers various teams to know the intellectual and human resources other teams have, which different teams can use. In other words, they can collaborate to solve any aspects by sharing knowledge and resources. As one of the industry experts and one academic leader who participated in the programme observed:

"…Collaboration is vital to solving problems because every team may not have everything they need. For example, a team may have a student who is very good at solving mathematical equations and another team may have someone good at using the software. So, they can collaborate and use each others knowledge and skill."

Engagement with stakeholders offers insights into the complexity and intricacies of the problems. Students can also benefit and learn from the experiences and expertise of the stakeholders, particularly from industry experts.

However, refinement of design brief and presentation of design brief (PI = 4.20), and finalisation of design brief (PI = 4.31) are found to be significant steps in this stage. According to two of the instructors and two industry experts:

"… presentation of the draft design brief helps improvement and refinement from the feedbacks and comments of their peers, instructors and industry experts. Also, the final design brief delineates the objectives, scope and methodology of the work…. the students now know what exactly to do and how they should do it. So, these are very crucial steps in the learning process."

Stage 4: Idea generation and solutions

The fourth stage consists of the generation of ideas and engineering concepts, engagement with technical experts, the transformation of concepts to alternate solutions (design or products), and evaluation of the alternate solutions. According to the respondents' perception, generation of ideas and engineering concepts (PI = 4.16), the transformation of concepts to alternate solutions (design or products) (PI = 4.24), and evaluation of alternate solutions (PI = 4.03) are significantly important. These perceptions are also corroborated by the instructors. As one instructor pointed out:

"…I find students really get engaged seriously and deliberate a lot during this idea generation stage. This step provides them to express their ideas, and opinions and also appreciate each other's idea."

Also, two of the instructors observed:

> “...During the development of alternate solutions, we find the students show their innovativeness and ingenuity. … they get engaged with literature, different sources of knowledge, different existing products, etc.… they really enjoy this step and learn.”

Similarly, one of the instructors said:

> “…I found during the evaluation of alternate solutions step they [students] argue a lot…[but] also try to be rational and logical to find different merits and demerits of the solutions. Definitely, they learn significantly… at least how to evaluate different solutions.’

However, engagement with technical experts although fairly important (PI-3.72), according to the industry experts the impact on student learning seems to be limited.

Stage 5: Final design/development of product and showcasing

Design of sustainable engineering solutions or creation of the sustainable products (PI = 4.25) and showcasing the design or product for evaluation (PI = 4.21) constitute the fifth and final stage of the learning process before the final assessment. These two steps in the final stages of the PBL perhaps are the two most important ones as these culminate the students endeavour to a particular outcome and also make their effort to be visualised by other stakeholders or evaluators. According to some students:

> “… Coming all the way from understanding a problem to developing a solution really makes us learn how to learn and how to use our knowledge. It broadened our outlook and made us work together and learn from each other.”

Another student observed:

> “…Initially I was not sure and a bit sceptical. I thought about what I will learn and can I really bring out something as a solution with the help of…these [my team members] guys … but when I see people appreciated our work after our presentation I felt we are good. More than that we learned how to develop the solution and how to sell to the stakeholders.”

5 Discussion and Conclusions

The development of a methodology for offering PBL is a critical challenge and needs an iterative process. The concern was mostly on how the steps followed in the process should be effective and assist in effective student learning. Moreover, since the practice of PBL in undergraduate civil engineering education in not prevalent in South Africa, there is no benchmark to follow. Also, the other challenge is to integrate the PBL with the OBE system so that the intended learning outcomes are realised and students can attain competency in the exit level outcomes. In the absence of a proper methodology or process, perhaps the focus and the outcomes of PBL might get astray. Therefore, the study was aimed at developing a methodology to deliver PBL to civil engineering students. This study relied on the action learning approach and lessons learned from the delivery of the PBL through a series of workshops. Also, the perceptions of the participating students and instructors as well as other stakeholders such as industry partners were sought and analysed to reinforce the findings from the lessons learned from the workshops. It is found that five sequential stages can assist in the effective and successful implementation of the PBL and attainment of learning outcomes. The first stage is the pre PBL offering preparation, which includes contextualising PBL within the OBE, a reflection of prerequisite knowledge and skill of the students, selection of stakeholders and selection of complex problems in alignment with learning outcomes. The second stage consists of the formation and preparation of heterogenous teams to work on a complex problem, engagement among the team members, identification of sub-problems, and preparation of a design brief. Engagement among the members across the teams, refinement of the design brief, presentation of the design brief, engagement with stakeholders and finalisation of the design brief constitute the third stage of the learning. The fourth stage includes the generation of ideas and engineering concepts, engagement with technical experts, the transformation of concepts to alternate solutions (design or products), and evaluation of alternate solutions. Design of sustainable engineering solutions or the creation of sustainable products and showcasing the design or product for evaluation/ assessment constitutes the fifth and final stage of the learning process. The assessment will be conducted continuously at various stages such as after the preparation of the draft design brief, development of alternate solutions and development of the final solution/design/ product. However, some of the steps are perceived to be more significant than the others in the learning process although all the steps are observed to be relevant. For example, steps such as the selection of problems in alignment with learning outcomes, formation and preparation of heterogenous teams to work on a complex problem, identification sub-problems, finalisation of the design brief, generation of ideas and engineering concepts, transformation of concepts to alternate solutions (design or products), evaluation of the alternate solutions, design of sustainable engineering solutions or creation of the sustainable products and showcasing the design or product for evaluation are of significant importance. These steps could be considered as the milestones in the process while delivering the PBL.

It is also argued that the students can learn different cognitive learning attributes such as understanding complex problems, applying, analysing, evaluating, and design or creation, and exit level outcomes such as problem-solving, technical and conceptual competence, sustainability, teamwork and communication at different steps of the PBL delivery process. Also, the student outputs are generally assessed by use of an appropriate rubric that enables assessment of both the cognitive learning attributes and exit level outcomes at different stages of PBL, which makes the assessment an integral part of the learning process. This helps the students to engage actively and learn deeply. It is thus argued that PBL with the aid of such a systematic methodological approach or process can enable effective learning and achievement of learning outcomes (desired competency) among the undergraduate civil engineering students in the universities of South Africa.

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