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A conceptualised design-based research framework for a problem-based learning approach in a first-year engineering course

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ABSTRACT: Problem-based learning (PBL) is an instructional learner-centred approach that has initially been implemented as an innovative teaching and learning strategy to achieve specific objectives. This theoretical article, is a desktop literature review of scholarly work on PBL and it, therefore, proposes a revised design-based research (DBR) framework for implementing PBL in an engineering course with the aim to enhance the self-directed learning (SDL) of students. A synthesised generic design-based research (DBR) model of Van Wyk and De Villiers was adapted with the aim to integrate PBL as an appropriate choice for this research to propose a DBR framework. The motivation for developing the PBL approach for SDL as a performance achievement initiative indicates several educational benefits of the study. This adapted framework is problem-driven, since it provides for deliverables as real-life artefacts and generates dual outcomes; namely, real-world solutions and theoretical understanding to inform future design approaches in problem-based environments.

Keywords: Design-based research, engineering course, problem-based learning, self-directed learning

INTRODUCTION

Scholars argue that design-based research is used for studies with a cyclic nature to attend to intricate, and practical educational problems with the aim to yield theoretical understanding [1][2]. The rationale for applying a design research approach is to achieve dual aims; namely, to solve problems as educational practitioners and to discover new knowledge [3]. Adding to this view, Euler asserts that design-based research (DBR) determines the *manner* in which an objective can best be achieved through an *intervention* that needs to be developed [4].

The DBR approach has iterative cycles of design to test analysis and re-design in order to optimise the design and obtain a deeper understanding of the phenomenon that is being studied [4].

There is a continuous interaction between practitioners and researchers throughout the entire research process [5]. Therefore, design-based research focuses on solving complex real-world problems that play a vital role in education with the commitment of theory construction [5]. On this prospective, in the context of engineering: *the purpose of design-based learning is not that engineering students should design something; it is that they should learn from designing something* [6].

Problem-based learning environments provide opportunities for skills development when designing something. Problem-based learning (PBL) is an instructional learner-centred approach that has initially been implemented in innovative medical education at McMaster University in Canada and has since been adopted across the globe [7]. PBL is driven by a question of inquiry or ill-structured problem simulation that needs to be solved in teams where students take responsibility for their own learning [8]. It is essential for each individual to be actively involved in group decision-making where they share coherently what they have learned. Such knowledge must be applied back to the problem with re-analysis and resolution [7].

A PBL learning environment is problem-focused, student-centred, self-directed, self-reflective and facilitative [9]. When it comes to engineering, students are required to solve real-life problems to resemble engineering practice. The aim of this theoretical article is to critically engage in scholarly literature on whether design-based research could be used as an appropriate framework for implementing problem-based learning in a first-year engineering course towards self-directed learning.

THEORETICAL FRAME OVERVIEW

This section commences with a discussion on design-based research (DBR), problem-based learning (PBL) and metacognition in PBL as drivers towards self-directed learning followed by a proposed framework for implementing PBL in an engineering course.

Design-based Research (DBR)

Scholars referred to design science of education and design experiments first developed DBR as an inquiry phenomenon to deal with theoretical and methodological challenges in creating interventions in the classroom [10][11]. Latter, scholars, particularly Van Wyk and de Villiers [2], are of the opinion that DBR is an approach that seeks the impact and consequences of education research into improved practice [5][12][13]. Furthermore, DBR aims to solve complex, real-world problems as a genre of inquiry to education, while simultaneously developing a theory of understanding [1][5]. In addition, a quality DBR study involves real educational context; design and test of an intervention; mixed methods; multiple iterations; collaborative partnerships; theoretical understanding; insight with practical applications; and it impacts on the learning context [12]. Likewise, DBR involves collaboration and participation, is associated with innovative development of solutions, comprises iterative processes, involves dual outcomes (innovative product or intervention; and a set of design principles or guidelines to inform future decisions), has an impact on practice and theoretical contribution, and authentic artefacts are produced as part of practical interventions [2].

The authors argue that design-based research could be an appropriate approach for applying problem-based learning in a first-year engineering course towards the self-directed learning of students. As stipulated in the learning objectives of the first-year engineering course, these key features of DBR are embedded in the learning programme to enhance self-directed learning. Furthermore, the distinctive phases in DBR are analysis and exploration (problem identification), design and construction (design and test the solution), and evaluation and reflection (impact of the innovation) [1].

The outcomes of design research are *practically* a process and/or product (maturing intervention) and a *theoretical* understanding of the phenomenon under study [1]. Moreover, these phases as: the preliminary research phase focusing on context analysis; a prototyping phase with iterative design in mind and, finally, an assessment phase dealing with the evaluation and outcome of the investigation [13].

Figure 1 is an adapted DBR model with the following phases: problem analysis within real-world context; design solution; develop solution; evaluate in practice; and reflection, leading to dual outcomes. In this model the outcomes are specified and the interactive nature of all actions is indicated. Feedback on previous steps is indicated or *refined* and applied a synthesised DBR model in the context of developing and evaluating reality safety training for the South-African mining industry [2].

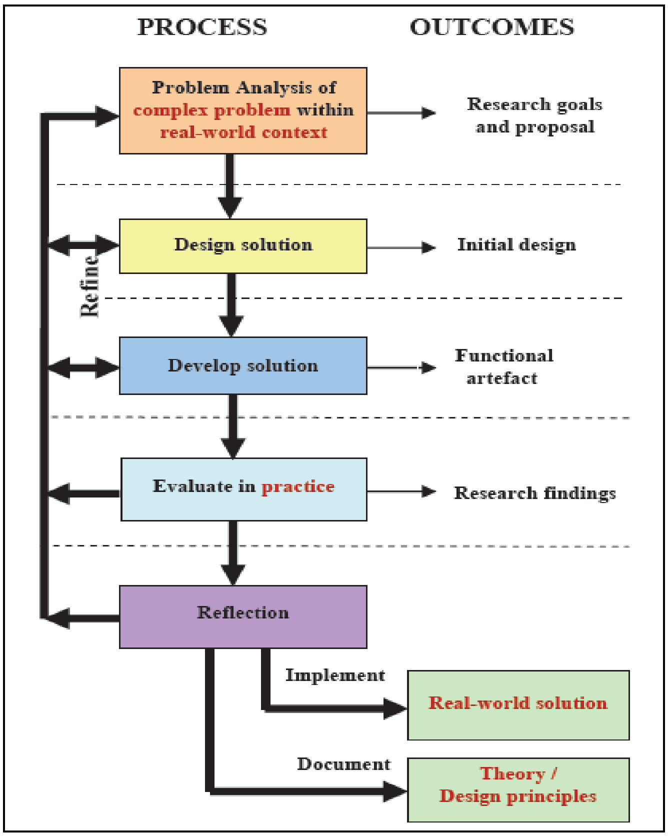

Figure 1: A synthesised generic model for design-based research [2].

Problem-based Learning

Problem-based learning was initially developed by the pioneer, Professor H.S. Barrows, in 1971 at the Faculty of Medicine, McMaster University in Canada with the aim to foster life-long learning [14]. PBL is based on sound educational theories and paradigms, and is theoretically underpinning in the constructivist assumptions about learning [9]. The emphasis is that knowledge is constructed and anchored where meaningful learning takes place in specific contexts. PBL provides a learning context where engineering students are exposed to solve authentic problems to prepare them for industry [6]. A PBL learning environment is focused on the problem of inquiry; it is student-centred; self-directed and self-reflective since it is facilitated with the aim to guide students [6]. PBL, as an instructional learner-centred strategy, empowers the integration of theory and practice with the simultaneous development of knowledge and skills to solve ill-structured problems [7]. Moreover, PBL provides for developing group learning objectives and skills development, such as analysis, hypothesis generation, decision-making, problem-solving and evaluation in *tandem* with developing group and communicating skills [15]. Facilitation is crucial in PBL in the sense to direct students in their learning processes. A critical attribute of PBL is to ensure ownership on the part of students since they need to be engaged and intrinsically motivated to solve authentic problems [6].

Different PBL models organise elements in teaching and learning differently and provide for variation in the general framework [16]. PBL is mainly categorised according to two types; namely, pure PBL and hybrid PBL. The pure PBL model is fully implemented as based on the McMaster model with the focus on interactive sessions, where students work in small groups without any lecturers or tutorial sessions, while the hybrid-PBL model is an integrated approach of lecturers involving teaching-learning activities, as well as tutorial sessions to facilitate students [17].

In the second stage of this study the hybrid PBL model is used as instructional strategy where students will develop practical projects in a first-year engineering course. Since the problem of inquiry is driving all PBL activities, the types of problems involved in practical engineering are outlined in accordance with some attributes [6][18]: workplace problems are ill-structured and include aggregates of well-structured problems; ill-structured problems have multiple, often conflicting goals; ill-structured problems are solved in many different ways - success is rarely measured by engineering standards; most constraints are non-engineering; problem-solving knowledge is distributed among team members; most problems require extensive collaboration; engineers primarily rely on experiential knowledge; engineering problems often encounter unanticipated problems; engineers use multiple forms of problem representation and they recommend more communication skills in engineering curricula.

The Role of Metacognition in Problem-based Learning

Metacognition involves the ability to think about our own thinking; and tasks at hand; and select appropriate strategies with the aim to control all mental activities, reflect on actions involved in a task and enhance deep learning [19]. Metacognition involves various types of knowledge; namely, knowledge of a task and strategies and self-knowledge. Embedded in metacognition is explicit planning, continuous monitoring and critical evaluation of one's own cognitive processes. Furthermore, metacognitive ability plays a critical role in the successful learning of students when it comes to mental activities, such as reasoning, comprehension and problem-solving [20].

In view of latter sentiments, the role of metacognition in student-centred environments, such as PBL enables students to perform better. This view on metacognition is that PBL may result in *significant metacognitive development* in undergraduates when compared to other types of teaching-learning approaches that do not mainly focus on solving real-life problems, since a high level of reflective performance is required [21]. Therefore, a high level of metacognitive monitoring and control is required where high level problem-solving skills are needed to scaffold the solving of complex problems [22]. This is especially true of engineering students to solve real-life problems. Metacognitive skills should be taught in cohesion with problem-solving activities, since problems are *a critical aspect of PBL* [9]. On this notion, metacognitive skills are an intrinsic part of the development of engineering students, since they need to solve real life problems and should be critical thinkers and innovators [23]. As a result, these scholars emphasise that engineering students need to develop such skills as early as possible, and provision should be made for corresponding teaching and learning environments.

PBL as an Accelerator for Self-directed Learning

PBL, as a teaching-learning strategy, is a means of directing all the phases and processes involved in project development (planning, design, development and evaluation). It is a compelling task to carry out a joint project where accountability, responsibility, knowledge and skills are shared among students. Scholars are of the opinion that PBL may provide opportunities for students to develop self-directed learning skills where they are actively involved in integrating their ideas to generate a final solution. Self-directed learning is a key component of students in higher education and adult learning to direct their own learning processes with the aim to succeed [24][25].

Self-directed learning is …*a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes* [26]. Zimmerman captures the idea that SDL *refers to self-generated thoughts, feelings, and actions that are planned and cyclically adapted to the attainment of personal goals* [27].

In fact, scholars posit the SDL approach as an important endeavour in advancing education environments, because of the unique characteristics of face-to-face and on-line environments as physical and social inclusive phenomena [28][29]. SDL comprises a deliberate ability to control and manage one's own learning and actions in order to make informed decisions, to select appropriate learning material, and reflect on learning processes and experiences [25]. Some attributes of a highly self-directed learner involve: setting goals; viewing problems as challenges; making informed decisions; showing initiative and persistence in learning; accepting responsibility for one's own learning; having the ability to learn independently; reflecting on and evaluating one's own learning processes and developing a plan for completing work [30]. Since students own their learning and direct their activities, they are able to persist in solving complex problems and create novel work of high quality [31]. As far as engineering is concerned, the development of projects encapsulates opportunities for students to be actively involved in taking ownership and responsibility for particular tasks and activities. The International Engineering Alliance (IEA) emphasises that individuals and teams need to take ownership of their tasks with the aim to enhance independent learning [32]. Additionally, PBL may assist engineering students in integrating ideas and generating a final solution. Such skills should be developed from the first year onwards [33]. The development of self-directed students should, therefore, be a strategic priority of universities, especially for engineers, to provide high quality teaching and learning.

For this theoretical article, SDL is viewed as an overarching concept related to an approach that is directed to learning and performance achievement. In a nutshell, SDL is designed on three distinctive components; namely, personal attributes, learning process and learning context. Firstly, the personal attributes comprise learners' motivations for taking responsibility for ownership of learning, and using cognitive strategies and resources to achieve personal gains. Secondly, autonomous learning processes enkindle the intended learning. Finally, the context in SDL is crucial and influenced by two factors; the design features and support structures as factors in processes towards self-directed learning in a conducive environment. A proposed DBR framework is outlined in the next section.

A PROPOSED DBR FRAMEWORK FOR IMPLEMENTING PBL IN AN ENGINEERING COURSE

The authors adapt the synthesised generic DBR model [2] with the aim to integrate PBL within DBR in a framework as an appropriate choice for this research towards SDL. Their model is problem-driven, it makes provision for deliverables as real-life artefacts and generates dual outcomes; namely, real-world solutions and theoretical understanding. This research aims to propose a conceptualised design-based research framework for problem-based learning to support the development of engineering artefacts. The framework is presented in Figure 2.

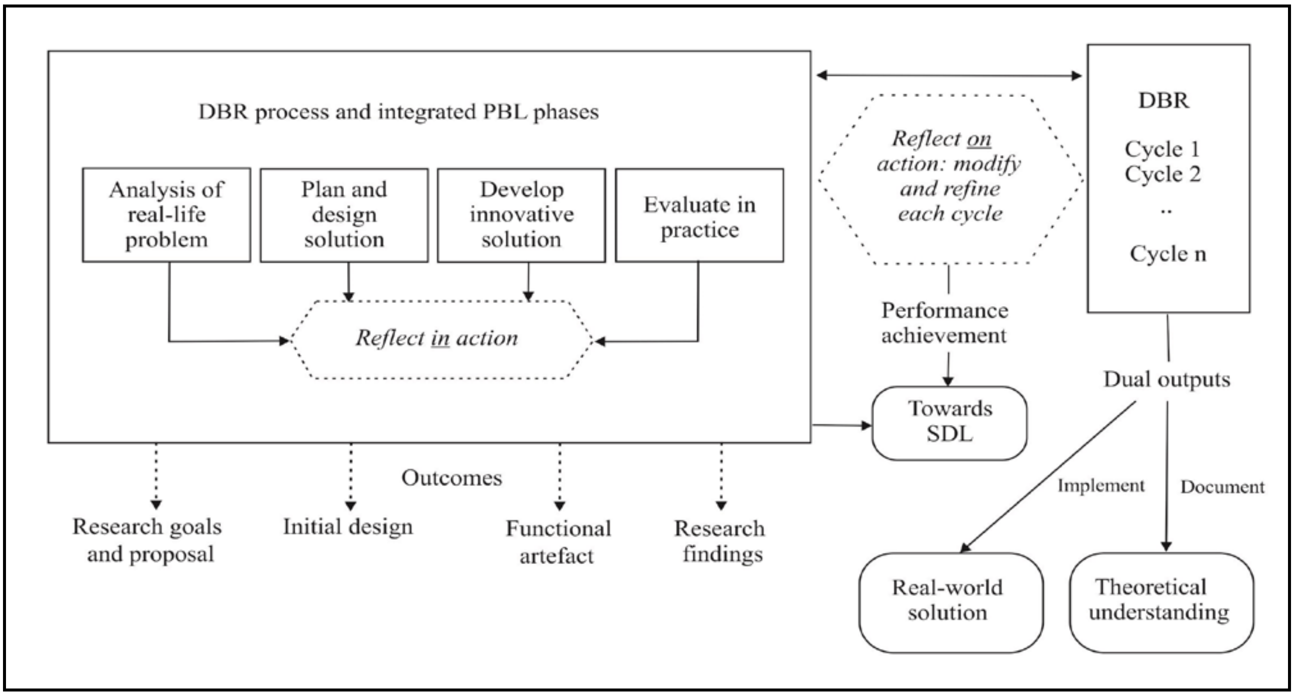

Figure 2: Integrated framework presenting PBL phases within design-based research towards self-directed learning.

Various processes, phases, activities, outcomes, outputs and opportunities for performance achievement towards SDL are portrayed in this framework. Each one is succinctly outlined:

1. DBR process and main phases: as part of the DBR process, four rectangles represent four main phases in PBL; namely, analysing a real-life authentic problem, planning and designing the solution, developing an innovative solution and evaluating the solution in practice.

2. Reflection: since metacognition is crucial in PBL, it is represented as *diamonds* in Figure 2 to indicate various types of reflection as checkpoints. Reflection *in* action and reflection *on* action were initially mentioned by Schön [34] and these are applied in this integrated DBR framework. Reflection *in* action involves reflection during an action (phase) without interfering, while reflection *on* action refers to *looking back* to understand what has happened, learn from past experiences (previous DBR cycles) and *looking forward* to meet challenges and modify and refine subsequent cycle(s).
3. Iterative cycles: embedded in this framework is the iterative cycles of DBR on the right-hand side. The iterative cycles are not merely an infinite number of instances, but rather based on specific and critical decisions and informed judgement to enhance, improve and re-design an artefact.
4. Outcomes of each phase: specific outcomes of each PBL phase and the DBR process are indicated by dotted arrows at the bottom, and involve the following: concrete research goals as a result of problem analysis; detailed design of the solution; development of a functional artefact and research findings to answer research question(s).
5. Performance achievement: PBL may be an accelerator for students to develop self-directed learning skills. While developing a project, students need to develop and/or apply various skills; for example, setting goals, learning independently, managing one's own learning processes and reflecting on the learning activities. Consequently, both reflection *in* action and reflection *on* action may contribute towards implicit SDL skills development and performance achievement, since such development may be a function of time (according to Knowles, SDL is a process [26]) and does not necessarily provide tangible outcomes; however, students' responsibility in learning may be enhanced.
6. Dual outputs: the completion of the final DBR cycle results in dual outputs; namely, the implementation of a real-world solution and the formal documentation and theoretical understanding of the phenomenon under study represented by the terminator symbols at the bottom on the right.

Design-based Research Framework in the Context of Engineering

Such a framework may render support to the development of prototypes, engineering projects or work in progress, and may also enhance students' responsibility in learning.

Analogous to engineering prototypes: a prototype is an initial model or product, build and tested according to specific requirements. Prototypes and artefacts are developed with the aim to solving a specific problem, developing requirements and translating requirements into specifications, evaluating new designs, reflecting on previous problems, learning from past experiences, meeting unexpected challenges and developing a final product or system according to all requirements. Scholars mention that, owing to limited domain knowledge, novice engineering designers sometimes lack strategic frameworks for problem-solving, such as prototyping. Furthermore, they assert: *When reflecting on their projects however, participants recognized the importance of using prototypes during all phases of the engineering design process* [35].

The re-design of artefacts is important in engineering to ensure that high-quality products are developed. In the context of engineering, the value of repeated and guided reflective practices to fully conceptualise prototypes or to enable novice engineering designers to show progress in project development is emphasised. Furthermore, developing work in progress, prototypes and projects in an iterative manner may elaborate on the depth and breadth of novices in terms of problem scoping, conceptual and procedural knowledge and refinement of several ideas [35].

Responsibility in learning: engineers are required to take responsibility for specific projects to be finalised on time, which involve the required cost, scope and quality. Applying the DBR framework for a problem-based learning approach may provide such opportunities for first year students to be responsible and accountable for specific tasks.

Project development in the second stage of this research: as part of the DBR cycle, first year engineering students will be required to develop an engineering artefact involved in a generic introductory module for mechanical and nuclear engineering; chemical and minerals engineering; electrical, electronic and computer engineering; industrial engineering or electromechanical engineering. Students will be required to work in teams as part of PBL. About 350 to 400 male and female students annually enrol for this module. The researchers need to reflect *in* action and *on* action to modify and refine subsequent cycles, where PBL is implemented with the aim towards students' development of SDL.

CONCLUSIONS AND FUTURE WORK

This theoretical article conducts a desktop literature review of scholarly work on PBL and, therefore, proposes a revised design-based research (DBR) framework for implementing hybrid PBL in an engineering course with the aim to enhance the self-directed learning of students. The context and purpose of design-based learning is not that engineering students should design something, they should rather learn from designing something through the learning programme. In order to achieve this purpose, problem-based learning environments provide opportunities for skills development when designing *the product through the objectives of a project*. In this conceptual article, the researchers have attempted, through extensive and critical engagement in scholarly literature, to determine whether design-based research could be used as an appropriate framework for implementing problem-based learning in a first-year engineering course towards self-directed learning.

After extensive literature reviews and work-related experiences, an outline of an integrated DBR framework presenting elements of PBL aligned with the first-year engineering course learning objectives to expose and improve students' problem-solving skills. The purpose of overall project is to use the integrated DBR framework, by following a hybrid PBL teaching strategy to solve complex real-life problems to foster the self-directed learning of engineering students. In the second stage of the proposed research study, the proposed integrated DBR frame in the hybrid PBL strategy will be used as an instructional approach by means of which students will develop practical projects in a first-year engineering course.

The research team is of the view that if this applied synthesised DBR model is aligned with the learning objectives of the first-year engineering course, it will improve students' self-directed learning substantively. It is, therefore, the intention of the research team, through this objective, to employ the integrated DBR framework presenting elements of PBL aligned with the first-year engineering course learning objectives in order to measure whether there are significant improvements in the problem-solving skills and self-directed learning of students. In the second stage of the overall study, the team will explore, through empirical inquiries, whether a hybrid PBL instructional strategy within the DBR frame is an accelerator of students' problem-solving skills in real-life projects towards self-directed learning.

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