

# IMPLEMENTING PBL IN A FOUNDATION PROGRAMME MATHEMATICS CLASSROOM: RELEVANCE OF PROBLEMS EXAMPLES

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**ABSTRACT:** This paper attempts to address the question of relevance of mathematical problems that characterised a problem-based learning (PBL) approach in a foundation programme (FP) mathematics classroom. Lebow's (1993) criteria were used to conduct a content analysis of the types of mathematics problems privileged in the FP's classes. The constructivist theory of learning as proposed by von Glasersfeld (1995), Vygotsky (1978) and Freudenthal's (2000) Realistic Mathematics Education (RME) approach are also invoked to critique the design of the problem tasks. The findings suggest that, to greater or lesser extent, the purposefully selected examples fulfil the requirements of the conceptual frameworks outlined by being problem-centred, learner-centred, real-life oriented, context-bound, open-ended, amenable to multiple solution strategies, collaborative and relatively complex or even messy to the learners, and thus encouraging critical, metacognitive reflexivity and out-of-the-box thinking. The pedagogy contrasts, somewhat, with the teacher-centred traditional lecture methods frequently experienced in high school.

**Key words:** problem-based learning, RME, second chance learners, foundation programme, educationally disadvantaged.

## INTRODUCTION

Considerable research has been carried out on the role that a problem-based learning (PBL) approach can potentially play in supporting collaborative learner-centred pedagogy in various disciplines, different educational levels and in a variety of contexts (Savery, 2006). In PBL students working in collaborative groups learn by resolving complex, realistic problems under the guidance of educators (Allen, 2011). Such collaborative learning can have a positive effect on student understanding of mathematics concepts, problem solving skills, academic achievement and affect (e.g. Abdullah et al., 2010; Fatade et al., 2013; Karatas & Baki, 2013; Padmavathy, 2013). However, very limited research has occurred in higher education foundation programme contexts about the nature of mathematics problems that fosters positive learning outcomes. For the purposes of this study, a foundation programme (FP) is considered to be a post school bridging programme that provides a second chance to students from educationally disadvantaged backgrounds for them to improve their National Senior Certificate (NSC) results in mathematics and science in order to access higher education studies in science, technology, engineering and mathematics (STEM) programmes. In a sense, such a programme acknowledges upfront the existence of an articulation gap between school and university mathematics more critically so among learners from historically disadvantaged population groups in under-resourced, non- or low fee-paying schools. A historically advantaged university (HAU), in South Africa, offers a highly selective mathematics (and science) foundation programme to support students who passed their matric, and therefore have the potential, but narrowly missed the cut-off points in the gateway subjects for them to be admitted into STEM programmes. This intervention programme was part of the university's broad strategy to deconstruct and redress imbalances of the past and to become more inclusive in student demographic profile. It was therefore an important lever of the university's self-transformation agenda.

The central role played by mathematics (and science) in a country's economic development is evident in the designation of these subjects by the World Economic Forum (WEF) as efficiency enhancers of global knowledge-based economies (Schwab, 2016). This designation has brought the quality of the teaching and learning of these gateway subjects into sharp focus worldwide. This scrutiny evinces the importance increasingly attached to country rankings in international benchmark tests such as the Programme for International Student Assessment (PISA), the Trends in Mathematics and Science Study (TIMSS) and,

more regionally, the Southern and East African Consortium for Monitoring Educational Quality (SACMEQ). WEF's global competitiveness reports claim to be the biggest ever global school rankings of 76 countries 'based on test scores in maths and science derived from PISA, TIMSS and TIERCE (for Latin America) (Coughlan, 2015). The PBL approach was adopted as the signature pedagogy for the foundation programme not just to improve the NSC marks but also to equip students with academic literacy skills, critical thinking skills and study ethos necessary for epistemological access with success in higher education (Morrow, 2009). This paper focuses on the mathematics classroom component of the foundation programme.

## **THEORETICAL BACKGROUND**

PBL is an enquiry-based, constructivist approach to curriculum and instruction that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop viable solutions to defined problems (Savery, 2006). Barrows (1992) concurs that PBL is one of the best exemplars for a constructivist-learning environment. Constructivism on the other hand is a philosophical view on how we come to understand or know. It has three primary propositions. Firstly, it proposes that understanding occurs in our interactions with the environment. That is, knowledge is actively constructed by the individual and knowing is an adaptive process which organises the individual's experiential world (Karagiorgi & Symeou, 2005, p. 17). Secondly, cognitive conflict is the stimulus for learning and determines the organisation and nature of what is learned through the Piagetian equilibration processes of accommodation and assimilation. (Also typical of messy, non-routine problems encountered in mathematical modelling). Thirdly, cognitive knowledge evolves through social negotiation and through the evaluation of the viability of individual understandings. That is, other people are the greatest source of alternative views to challenge our currently held views (von Glasersfeld, 1995). Vygotsky (1978) uses the metaphor of bridging the Zone of Proximal Development (ZPD) where individual students have the opportunity to move across from the current level/form of understanding to a new level/form of comprehension with the scaffolding of their own effort and prior understandings or those of more knowledgeable others.

Lebow (1993) identifies eight constructivist principles that resonate with a PBL approach: 1) linking all learning activities to a problem or task; 2) supporting learners in taking responsibility for the overall problem or task; 3) designing of authentic tasks in which learners can engage in mathematical activities where the cognitive demands are consistent with the way a mathematician would work; 4) designing the tasks and learning to reflect the complexity of the learners' environment enabling some form of cognitive apprenticeship; 5) giving learners the ownership of the problem solving process and shifting the educator's role to that of facilitating learners' thinking; 6) designing a learning environment to support and challenge the learners to become effective thinkers and workers; 7) encouraging the testing of alternative views and contexts to reinforce knowledge as socially distributed in collaborative learning communities; and 8) encouraging and supporting reflection on the learning process and content.

## **RESEARCH METHODOLOGY**

The purpose of this paper was to gain an understanding of the nature of mathematics PBL problems used in a foundation programme. The following research question guided the study: What was the relevance of problem tasks in the implementation of PBL in the FP mathematics classroom? To answer the research question the researcher adopted a conceptual approach in which qualitative content analysis of selected tasks was conducted to gain insight into the nature of problem tasks presented. Two exemplar problems were selected for analysis, one at the beginning of the academic year and another towards the end of the academic year.

## **RESULTS**

### **Problem 1: The Security Guard problem**

After the main introduction of the PBL ground rules students were immediately divided into groups of five to work on an Amazing Race problem, a map reading problem requiring collaborative work to follow given directions until they find the hidden treasure. See Figure 1.

The problem could be analysed in terms of Lebow's (1993) criteria of PBL as follows:

- a) Linking all learning activities to a problem: the introductory problem was only a beginning of a long journey of the FP year. All learning activities for the first day were linked to the problem task. In that regard Criterion 1 was adequately met.

You are part of a security group that receives the following request from your university/company.

The western border of the Education Building has to be secured between 08:00 and 09:00 on 17 February. The request is that two guards have to patrol Andringa Street between Merriman and Crozier Streets. The two guards must start at a central point in Andringa Street and walk in different directions to the two corners respectively. At the corners, they turn around and walk back to the starting point where they pass each other. The guards therefore first walk away from each other towards the opposite corners where they turn around and approach each other. They then pass each other and approach the opposite corner where they turn around to repeat the process.

Plan, as a group, how the guards are going to patrol Andringa Street. Do a trial run and measure the distances and time taken between the turning points and the point where they pass each other.

**Figure 1: Security Guard problem**

- b) Supporting learners in taking responsibility of the overall problem or task. The learners were divided into small groups of five or six and assigned different roles as outlined in text box 1. Since each learner in a group had a role or responsibility to discharge the fate of the resolution of the problem lay in the hands of the learners.
- c) Designing of authentic tasks in which learners can engage in mathematical activities: the fact that security patrols were a common occurrence in the urban set up made the problem authentic, though somewhat distantly, given that the precincts of the education building were not as heavily patrolled by security guards as the problem might imply at first glance. It was therefore a realistic problem though not identical to the real life conditions at the site of learning. Cognitively speaking the demands of the tasks were challenging enough to engender meaningful intellectual and mathematical engagement with the problem. That Andringa Street, Crozier Road and Merriman Avenue were well known streets around the Education Building added to the experience of problem authenticity.
- d) Designing tasks that reflect the complexity of the learner's environment enabling some form of cognitive apprenticeship: The absence of reasons for securing the street between 08.00 and 09.00 rendered the problem less realistic on paper (i.e. contrived) but more open-ended, open to multiple-interpretation and multiple solutions, and therefore cognitively complex enough. That the distances to be covered, and the walking speeds of the guards were not given further opened up the problem to multiple solution strategies and a myriad of assumptions to be drawn up in the solution process.
- e) Giving learners the ownership of the problem solving process and shifting the educator's role to that of facilitating learners' thinking: That the problem was to be solved in groups where members had designated roles to play placed the responsibility of the problem solution process in the hands of the learners. The teacher's role was of facilitating rather than directing learners' thinking. The students would only come back for clarification of the task rubric and left to chart their own path group by group.
- f) Designing a learning environment to support and challenge the learners to become effective thinkers and workers: the ethos of respecting everyone's contribution to the problem solution was emphasised to enable all learners to feel comfortable to contribute and be prepared to critique or be critiqued by others, without taking offence. Although this was not self-evident in the task itself it was part of the classroom culture of effectively reaching a solution to the problem as a team.

- g) Encouraging the testing of alternative views and contexts to reinforce knowledge as socially distributed in collaborative learning communities: That there were no specific measurements given *a priori* in the task opened up a dialogical space for learners to make conjectures and test them in the public opinion of other group members. Those other group members would be equally entitled to proffer and defend their own (alternative) views in the same collaborative learning space.
- h) Encouraging and supporting reflection on the learning process and content: Students were encouraged to come up with solutions by means of group consensus, which can only emerge in a context of individual and collaborative self-reflection. That there were no pre-set answers in the 'messy' problem task enabled learners to reach consensus without expecting the teacher to be the final arbiter, save their own justifications.

### **Problem 2: The Research Project Problem**

In the latter half of the academic year students were assigned a group research project to complete over a six-week period culminating in a research project report and PowerPoint presentations. Within a group, students had to rotate roles introduced at the beginning of the year, this time with a lot more experience. The problem to be solved was an investigation of factors crucial for predicting academic success at the HAU as shown in Figure 2.

- Your group belongs to a consulting agency that analyses data for different companies. The Rector's Management Team at the HAU has approached you to help them analyse data that they have collected. They want to know what factors best predict academic success at the University and expect you to write a report and do a PowerPoint presentation on your findings. Use the data and formulate different hypotheses based on the different factors available.
- Present the data using different forms of representation.
- Consider the similarities and differences that different representations highlight.
- Determine which representation reflects the information that you want to convey the best? Only include this representation in your report and PowerPoint presentation.
- Use your analysis to accept or reject your hypotheses.

**Figure 2: Factors predicting academic success at the HAU**

The students were required to first write and submit an introductory essay on the uses and/or abuses of statistics, how data were collected and how they would be statistically analysed/represented. To compile the report the students had to obtain recent first year results for STEM related programmes at the university. The guidelines for the group PowerPoint presentation were that the investigators/researchers should draw conclusions based on facts/evidence and not opinions. The students were they required to present their reports in a captivating, creative or engaging manner using computer skills acquired in the programme. The problem could be analysed as follows in terms of Lebow's (1993) criteria of PBL:

- a) Linking all learning activities to a problem: The research project was based on a problem that learners had to work on collaboratively to resolve. All sub-tasks of the project were organised to address the research hypotheses. To that extent Lebow's first criterion of linking all learning activities to a problem was satisfied.
- b) Supporting learners in taking responsibility of the overall problem or task: The group structure that had been introduced at the beginning of the year was used as the *modus operandi* for resolving the problem. To that end, every learner had a contribution to make towards the realisation of the group's common goal.
- c) Designing of authentic tasks in which learners can engage in mathematical activities: That the data to be analysed pertained to factors pertinent to first year success at the HAU in which the students were enrolled for the bridging programme and into which they would be

admitted if they passed connected the problem authentically to the students' ambitions. Student data to be analysed, for example, included the demographic profiles of the students such as, race and home language of a student. That these issues are often critical sources of friction at the HAU meant that students associated with them intimately as determinants of success that needed confrontation, critique and transformation in the ecology and institutional culture of the HAU. Given that the majority of the students in this programme were historically and educationally disadvantaged the task would make them genuinely and sensitively aware of their vulnerability in the academic socialisation processes of the HAU. In other words, it was a real-world problem they could strongly connect and identify with.

- d) Designing tasks that reflect the complexity of the learners' environment enabling some form of cognitive apprenticeship: The sensitive nature of the demographic and socio-economic factors reflected the complexity of the actual lived experiences of the learners' environment. This was more so in a country that still bears the scars of a racially divided past and continues to feature prominently as one of most unequal societies of modern times according to the Gini coefficient of income inequality (World Bank, 2007). That made the problem not only complex but messy. That learners were to identify independent and dependent variables from the data by themselves and apply statistical techniques such as correlational analysis to rebut or confirm their hypotheses was cognitively complex enough for the level of curriculum engagement expected. It also allowed students to think critically, analyse and solve complex, real-world problems as suggested by Savery (2006). However, students were not expected to carry out rigorous hypothesis testing which would fall outside the scope of their curriculum. One could therefore argue that they were exposed to quasi or informal hypothesis testing. They were, nevertheless, expected to come up with accurate predictions of academic success at the HAU using predictor linear equations, based on the data to understand the complexity of the academic environment they were aspiring to enter.
- e) Giving the learners the ownership of the problem solving process and shifting the educator's role to that of facilitating learners' thinking: Once again the collaborative execution of the research project enjoined the students to take ownership for the problem solution strategies. The students were, however, required to return to the facilitators to check if they were on the right track or to obtain advice from time to time. Hence, the role of the lecturers shifted palpably from that of direct instruction traditionally followed at high school to that of facilitating students' thinking and thereby steering them towards autonomy over the direction and pace of their own learning. This kind of facilitation resonates with the view of PBL as a vehicle for self-regulated learning (Malan, Ndlovu and Engelbrecht, 2014).
- f) Designing a learning environment to support and challenge the learners to become effective thinkers and workers: The fact the students were expected to work on their own and at their own pace for a duration of six weeks provided them with the opportunity to trial run different solution paths and justify their veracity to the group. That didactic setting created opportunities for self-reflective engagement and scientific argumentation typical of effective problem solving and therefore supportive of metacognitive thinking.
- g) Encouraging the testing of alternative views and contexts to reinforce knowledge as socially distributed in collaborative learning communities: The quantitative exploration of multiple latent variables as likely to bear on a student's academic success necessarily compelled students to compare alternative relationships (correlations) between dependent (predictor) and dependent (success) variables. The group ethos was to treat each member's contribution respectfully and on its merits rather than on preconceived assumptions.
- h) Encouraging and supporting reflection on the learning process and content: Through their regular (weekly) meetings, students we encouraged to reflect on their progress as a group about the statistical choices, the effectiveness/fairness of their individual contributions towards the group goal in both qualitative and quantitative terms. Groups would be expected to collectively evaluate (reassess) the comprehensiveness and relevance of their literature review, the relevance and accuracy of data collection, collation and analysis procedures, and the validity of conclusions drawn, to answering the research hypotheses.

## DISCUSSION AND CONCLUSION

PBL as an active learning instructional approach is a leading example of learner-centred education in which students co-construct knowledge through productive discourse practices (Hmelo-Silver & Barrows, 2006). Barrows (2000) underscores the fact that PBL is primarily premised on the use of ill-structured problems as a stimulus for learning. The challenge in this paper has been to examine the extent to which problems posed in the FP were constructivist, ill-structured stimuli of learning and amenable to multiple solutions. The findings suggest that, to a greater or lesser extent, the purposefully selected examples satisfy the requirements of the conceptual frameworks outlined by being problem-centred, learner-centred, real-life oriented, context-bound, open-ended, amenable to multiple solution strategies, collaborative and relatively complex or even messy to the learners, and thus encouraging critical, metacognitive/reflective and out-of-the-box thinking. The pedagogy contrasts, somewhat, with the teacher-dependent and teacher-dominated traditional lecture methods frequently experienced by the students in their conventional high school mathematics classrooms.

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