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Examining learning achievement and experiences of science learners in a problem-based learning environment

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Problem-based learning (PBL) is a facilitation strategy that has the potential to put learners at the centre of activity and to make them accountable for their own learning. However, the assumption is often made, during attempts to utilise PBL, that learners will acquire less information than learners who have been taught through direct, lecture-based strategies. The present work challenged this assumption by exposing experimental and control groups of Grade 10 science learners to different learning environments. Results showed that the PBL-taught experimental group did not sacrifice subject content. PBL learners scored significantly higher than their lecture-taught counterparts on selected questions in the post-test that were classified on Bloom's taxonomy as higher order questions. Through qualitative measures the study also probed the levels of enjoyment experienced by below- and above-average achievers who were exposed to PBL.

Introduction

Learner-centred, hands-on, activity- and inquiry-based learning strategies pierce the literature on constructivist-orientated science education (Scott, Dyson & Gater, 1987; Black, & Atkin, 1996, Windschitl, 1999). Transformational outcomes-based education also advocates a sharper focus on learner-centred pedagogy (HSRC, 1995; Malcolm, 1998). One of many teaching strategies, which has the potential to involve learners more and also make them more accountable for their own learning, is problem-based learning (PBL) (Savoie & Huges, 1994; Vernon & Blake, 1993; Schmidt, 1983, 1993). However, attempts to use such learner-centred strategies, especially PBL, often attract the criticism that learners acquire less content information than in traditional positivist classrooms (Gallagher & Stepien, 1996). This introduces the age-old debate of depth versus breadth of curriculum content coverage.

This study challenged the perception that learners acquire less information by testing the following hypothesis:

> Science learners who learn through PBL facilitation strategies acquire less information than science learners who learn through traditional expository teaching strategies.

The alternative hypothesis was:

> Learners who have learned through PBL facilitation strategies acquire the same amount of information as learners who learn through traditional expository teaching strategies.

In an attempt to add another dimension towards understanding the outcome of the tested hypothesis the following question was asked:

> Did learners who have been exposed to a problem-based learning environment enjoy the learning experience?

Relating learner-centredness and problem-based learning

There are two broad approaches on a continuum representing various teaching strategies, namely teacher- and learner-centred approaches. Killen (1998:v) contends that in some way it is an unfortunate set of labels, because learning, and therefore learners, should always be at the centre of learning. Nevertheless "these labels certainly convey the idea that in some approaches to teaching the teacher plays a more direct role than in other approaches" (Killen, 1998:v). He also reminds us that in a learner-centred approach the teacher still sets the agenda but has much less direct control over what and how learners learn in a less-structured, less-predictable learning environment. Although a multitude of meanings may be associated with the term learner-centredness, in this research it embraced John Dewey's observation that "true learning is based on discovery guided by mentoring rather than the transmission of knowledge" (Boyer, 1998:15). This interpretation of learner-centredness is consistent with a constructivist view of learning. The constructivist view of learning acknowledges the impact of prior learning and learners' preconceptions on the process of developing new understandings and knowledge (Yip, 2001; Scott *et al.*, 1987; Von Glaserfeld, 1993).

Pomeroy (1993) and Yerrick, Park & Nugent (1997) take the position that traditional secondary Science curricula are still dominated by teacher-centered pedagogy where transmitting a body of knowledge to learners through intelligible explanation is the main vehicle for delivering instruction. Instructional strategies such as direct instruction, deductive or expository teaching, which are typified by a lecture format used for whole class teaching, places a teacher at the centre of activity and accountability while learners passively have to absorb and memorise a critical mass of facts (Wubbels, Créton, Levy & Hooymayers, 1993; Ornstein & Hunkins, 1993). Rosenshine (1987: 34) explains that the emphasis in direct instruction is on "teaching in small steps, providing for student practice after each step, guiding students during initial practice, and providing students with a high level of successful practice".

One of many teaching strategies that has the potential to put learners at the centre of their own learning is learning through problem-based learning. West (1992) contends that the information humans gain from their daily confrontation with problems influences their thinking much more than information that was read or told. Several functions are associated with the term PBL. Firstly, PBL can be used as a basis for an entire curriculum through which subject content may be acquired. This strategy advocates starting with the problem as a learning trigger, rather than with problem-solving tools (Ross, 1991: 36-37; Schmidt, 1993:11). Secondly, PBL can be studied as a theme, for example by pre-service teachers where they learn about heuristics and algorithms for problem solving. A third way of using PBL is where teachers teach for problem-solving. In this research, PBL was used as a facilitation strategy through which science learners had to learn and demonstrate outcomes related to a theme on energy, energy efficiency and alternative energy resources. Learning through problem-solving in PBL may be defined as a process of using existing knowledge in an unfamiliar situation in order to gain new knowledge (Trowbridge, Bybee & Powel, 2000:33; Killen, 1998:106). Barrows & Tamlyn (1980:18) state a PBL problem "is not offered as an example of the relevance of prior learning or as an exercise for applying information already learnt in a subject-based approach".

The problems that are suitable for PBL are therefore not of the type that are suitable for multiple-choice questions, which have to be clearly defined, come with all the information needed to solve them and have only one single method for arriving at the answer. PBL problems should adhere to rigorous criteria, that is, they should (a) be authentic and credible, (b) be unstructured and open-ended, (c) require seeking, accessing and evaluating information from various resources, and (d) be complex enough to require considerable individual and peer-group effort (Claxton, 1999:32; Eason & Green, 1987:243). When problems are engaging, challenging and interesting, they encourage higher levels of comprehension and skill development than in traditional instruction (Albanese & Mitchell, 1993). A problem should be designed in such a way that it creates cognitive conflict which elicits spontaneous self-directed learning (De Grave, Boshuizen & Schmidt, 1996:323-324).

The rationale for using PBL in science education is embedded in various documented advantages, some of which are listed below:

- By developing meaningful solutions to problems, learners are lead to a deeper understanding of the subject matter (McAllister, 1997).
- Learners are given the opportunity to develop qualities such as resourcefulness, patience, tenacity and independence (Fisher, 1987).
- PBL creates conditions that a) assist in the retrieval and activation of prior knowledge, b) provide a context for learning that may be similar to one in which the knowledge will be used later, and c) provide an opportunity to elaborate on information that increases retention (Schmidt, 1983, 1993; Wilkins, 1993).
- Since learners see their learning as a definite result of their own efforts, PBL can be stimulating, rewarding and fun (Schmidt & Moust, 2000).
- When combined with co-operative learning, which it was in this research, it adds the well-documented advantages of co-operative learning to the learning-process (Johnson & Johnson, 1990; Sharan & Sharan, 1987; Webb, 1991). Learners, for example, brainstorm possible solutions, draw on one another as resources and probe one another to reflect on premises. It also provides a supportive social learning environment which is much needed, since a problem-solving endeavour can be extremely frustrating and emotionally draining (DeLuca, 1992).

Research design and methodology

For testing the hypothesis a classical research design was used where experimental and control groups exposed to different interventions, were compared after they had written pre-tests and post-tests. Experimental groups were taught through the PBL strategy while the control groups were taught through an expository, lecture-based strategy. All participants were Grade 10 science learners from four different high schools, three in Gauteng and one in Mpumalanga. The four schools were selected through convenient sampling, since four of the eight principals approached granted permission to do the research in their schools. The principals were also requested to allocate two Grade 10 classes per school and to select which one could be used as an experimental and which one as a control class. Three months prior to the interventions, all participants wrote a pre-test to establish whether the experimental and control classes were statistically comparable before the interventions commenced. The pre-test results of the experimental and control classes were treated as two independent data sets and the p value of 0.0001 on the t test indicated that the experimental and control classes differed significantly. This posed the challenge of creating statistically comparable experimental and control *groups* within the initial experimental and control *classes*. The following set of criteria were used to create comparable experimental and control groups: a) only learners from the same school, b) the same gender, and c) with exactly the same pre-test marks were represented in the experimental and control groups. Of the initial 202 learners in the different schools, only 70 experimental and 70 control learners (N = 140) complied with these criteria and featured in post-test comparisons between experimental and control groups. Since the initial data sets of the experimental and control *classes* were treated as two independent samples, the sub-sets represented by the experimental and control *groups* were also treated as independent samples. Figure 1 illustrates the process of creating the comparable groups.

The duration of the school interventions was 20 school days with an average of three hours in the science class per week. The same teacher was responsible for teaching both the experimental and the control group in a particular school. The teachers in the four schools all had exactly the same qualifications, had received six months pedagogy training by the researcher, and had the same instructional materials, resources, apparatus, learning-task plans and timeliness for the two different interventions they had to implement. It can be assumed that if the same teacher had been responsible for the interventions in all four schools that the validity of the results might have been enhanced. However, this is an assumption and is the reality of doing *in vivo* research that introduces the complexities of real classrooms as opposed to *in vitro* research in laboratory conditions.

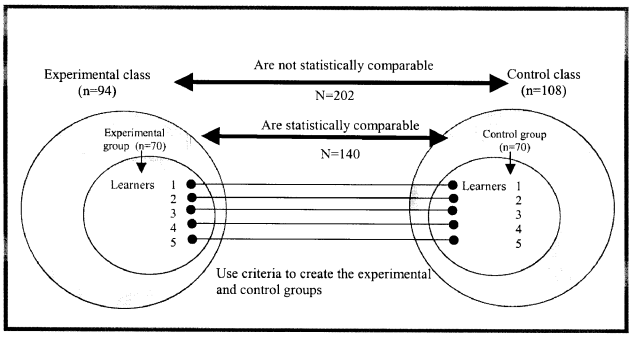

Figure 1 Process of creating statistically equivalent experimental and control groups in each school

Pre-tests and post-tests were equivalent, but not identical. If learners were given exactly the same test for pre-test and post-test purposes, the pre-test could have prepared them for the post-test to an extent. To avoid this problem the same concepts were used in the tests, but they were formulated differently and were also placed in an alternative context. The questions containing similar concepts were also pitched at the same cognitive level of the Bloom taxonomy and validated by the science teachers at the participating schools. Teachers who were responsible for the interventions did not see the pre-test or the post-test so as to avoid a teaching-for-the-test effect. The post-test was written one month after the interventions. To counter any test anxiety, learners were told that the test marks would not contribute to any official final science marks. Pre-tests and post-tests were marked by an experienced teacher who was not attached to any of the four schools involved in the interventions. The researcher moderated the marked pre-tests and post-tests of each participant in the experimental and control groups.

To answer the research question, data of both quantitative and qualitative nature were gathered. Quantitative data were derived from one of the questions in an attitude questionnaire completed by experimental group learners. Qualitative data were obtained from written comments made by the 70 learners who had experienced PBL.

Research interventions with the experimental and control groups in the authentic context

Table 1 summarises the main differences between the interventions with the experimental and the control groups.

Testing the hypothesis: Statistical data presentation and analysis

Since the same pre-test marks were used as one of the criteria to create statistically comparable groups, all the calculated values were almost identical as indicated in Table 2.

The mean post-test total (in percentage) of the experimental and the control groups were compared after the different interventions using a t test for independent groups (See Table 3).

Table 3 indicates that the total mean score of 65.13% for the experimental group was higher than the total mean score of the control group, which was 62.72%. However, the p value confirmed that the difference in total mean scores was not significant. This result rejects the hypothesis and accepts the alternative hypothesis which stated:

Learners who have learned through PBL facilitation strategies

Table 1 Main differences between the experimental and the control group interventions

Experimental group intervention	Control group intervention
Approach: Learner-centred approach with focus on content acquisition and higher order thinking skills development. Learning theory: Constructivism Appropriate terms: Learning task and learning facilitator	**Approach:** Teacher-centred approach with focus on knowledge acquisition and content-coverage. Learning theory: Positivism Appropriate terms: Lesson/lecture and teacher
Creation of a conducive learning environment: Problem was presented to create an authentic learning context. (See Appendix 1)	**Creation of a conducive learning environment:** No problem was presented. The teacher announced the topic and sub-topics to be studied prior to each lecture.
Learning materials: A resource kit with minimum information and relevant materials. A research corner in the laboratory with a variety of books and Grade 8–11 textbooks. An arrangement with the school library to use the Internet during breaks and after school for this project. Internet addresses and additional references to resources to use in own searches.	**Learning materials:** Notes that were summarised by teachers containing all the information needed to do the exercises in the textbooks and worksheets. Each learner received a set of Grade 8–11 textbooks. Learners could also use any relevant resources if they wanted to. Typical end of chapter exercises and questions after each lecture. Transparencies to use on overhead projectors.
Learning facilitator role: Facilitator of learning. Gives feedback and emotional support to co-operative groups and individual learners where necessary. Learners are predominantly in control of their own learning. Facilitator monitors progress towards outcomes. "Guide-on-the-side".	**Teacher role:** Teacher teaches by presenting a lecture to the whole class simultaneously. Teacher plays the dominant role and is responsible for the learning of learners. Teacher asks questions and initiates discussions with the whole class. "Sage-on-the-stage".
Learner roles: In heterogeneous cooperative groups learners brainstorm ideas, hypothesise, draft action plan and decide on individual responsibilities. Facilitator monitors individual accountability, group functionality and overall progress.	**Learner roles:** Learners are passive recipients of knowledge. They listen to the teacher who asks questions, and complete the exercises using the notes (textbook). Learners are invited by teacher to ask questions.
Initiate the research. Use minimum resources provided in the resource kit as a point of departure. Identify, access and use additional resources. Learners are actively discovering, researching materials and constructing meaning from the resources.	Learners work mainly individually. Individual mastery, success and accountability are promoted. During the practical sessions they worked in groups for the duration of the session.
Scheduled co-operative group meetings to map their progress. Share new perceptions, knowledge, skills and values. 45-minute presentation of the problem-solution which was a working prototype device to the "representative" of Department Minerals and Energy, other class members and teachers in the school. 15 minutes question time and inter-group discussion.	
Feedback: Formative feedback: Learners get continuous feedback from cooperative group members, facilitator and a meta-learning checklist that was part of the resource kit. Summative feedback: Facilitator does PBL task debriefing and quality assurance of outcomes demonstrated.	**Feedback:** Learners get feedback from the teacher when the end of the chapter exercises are marked and if learners ask questions during the lectures. A working prototype model was built from a prescribed plan. The learners did not generate solutions, since there was no problem to be solved — just content to be covered. Learners did show their final models to other members in the class and teachers in the school, although all the models were similar. The final prototype of the model was the same for all the learners, since there was no problem to be solved. Actually, only the ability to work from a prescribed plan and the quality of the craftsmanship could be assessed.

acquire the same amount of information as learners who learn by means of traditional expository teaching strategies.

A per question analysis was also conducted for the experimental and control groups, to compare their achievement in the different types of questions. The marks allocated for each question are indicated next to the question number in Table 4.

The *p* values for questions 1 and 3 were smaller than 0.01. This means that the higher mean scores of the control group for these two questions were significantly higher than the mean scores of the experimental group. It seems that the direct instruction strategies enhanced performance in these two questions. Both of these questions were classified on the lower cognitive levels of Bloom's taxonomy. Question 1 is a knowledge-type question, while question three is a comprehension-type question. For questions 5, 9 and 10, the experimental group scored significantly higher than the control group. Question 5 was classified as an application-type question, whilst the other two represented the higher cognitive levels on Bloom's taxonomy. Questions 9 and 10 were synthesis and evaluation type questions, respectively.

Table 2 Pre-test results

	Experimental group (n = 70)	Control group (n = 70)	*t* test for independent groups (*p*)
Total mean value (%)	61.78	61.82	0.9699
Standard deviation	15.78	15.68	

Table 3 Post-test results

	Experimental group (n = 70)	Control group (n = 70)	*t* test for independent groups (*p*)
Total mean value (%)	65.13	62.72	0.1915
Standard deviation	11.55	9.85	

Table 4 Post-test results per question

	Experimental group		Control group		*t* test for independent groups (*p*)
	Mean	SD	Mean	SD	
Question 1 (4)	3.162	0.745	**3.536**	0.677	**0.0025***
Question 2 (5)	3.279	0.770	3.420	0.864	0.3158
Question 3 (5)	2.765	0.994	**3.942**	0.802	**0.0000***
Question 4 (5)	3.324	0.781	3.304	0.810	0.8880
Question 5 (5)	**4.059**	0.844	2.580	0.830	**0.0000***
Question 6 (5)	3.309	0.675	3.435	0.776	0.3128
Question 7 (15)	8.882	2.203	9.232	2.122	0.3459
Question 8 (10)	5.824	1.078	6.000	1.188	0.3645
Question 9 (6)	**4.515**	1.015	3.290	0.842	**0.0000***
Question 10 (10)	**6.544**	1.263	5.116	0.963	**0.0000***

* $p < 0.01$

Results from the attitude questionnaire and qualitative learner comments

Only the experimental group that was exposed to PBL interventions completed the Attitude Questionnaire. Owing to the limited scope of this article, only one of the questions will be highlighted and analysed. The question put to the experimental group learners asked simply "Did you enjoy the new method in the teaching of science?" On a 5-point Likert scale the respondents reacted as indicated in Table 5.

Table 5 indicates that the majority, i.e. 75.5% (53), of the experimental group learners enjoyed PBL. The next level of analysis was to establish how the above- and below-average achievers differed in their enjoyment of PBL. Learners who scored higher than the mean post-test score of 65.1% were labelled above-average achievers, whilst those scoring below the mean post-test score were labelled below-average achievers for the purposes of this comparison.

Fisher's Exact Two Tail Test (Fisher, 1935) was used to do the comparison in a two-by-two matrix. Learners who selected options 1 and 2 were grouped under the "not at all" category, whilst learners who selected options 4 and 5 were grouped in the "very much" category. Learners who selected the neutral option, which was 3, were not taken into account in this calculation.

The right tail test value indicates that the significance lies in one of the two right quadrants of the matrix. The particular extreme value at stake here is 37.4%. This means that the above-average learners had a significant preference for selecting the "very much" option. Twenty-six of the 70 learners who selected the "very much" option were above average and 10 of the above-average achievers selected "not at all". In other words, more than twice as many above-average achievers enjoyed learning through PBL, as opposed to the above-average achievers who did not enjoy PBL at all. This was a significant difference. For the below-average achievers, there was no significant difference between those who enjoyed PBL (16) and those who did not (18).

Table 5 Learner enjoyment of PBL

Did you enjoy the new method in the teaching of science?

Response options	Frequency count	Percentage
Not at all (1)	1	1.0
Not too much (2)	9	12.5
I do not know (3)	7	11.0
Quite a lot (4)	21	29.5
Very much (5)	**32**	**46.0**
Total	70	100

Table 6 Above- and below-average achievers' enjoyment of PBL

Do you enjoy this new method in the teaching of science?

Number of learners (%)	Not at all	Very much	Row percentage
Below average	25.0 (n=18)	23.5 (n=16)	47.5
Above average	14.5 (n=10)	**37.4*** **(n=26)***	51.9
Column percentage	39.5	60.9	100

Fisher's Exact Test (2 tail) (*p*): **0.042***
Right tail value (*p*): **0.046*** Left tail value (*p*): 0.986

* $p < 0.05$

To get a qualitative understanding of the empirical numbers, learners had the opportunity to comment in writing on "my experiences of this new method that was used to teach science". Learner comments that revealed insight into learner attitudes, experiences, enjoyment, or the absence thereof, are presented here. Before each comment, the post-test mark obtained by that particular learner is indicated.

(30%) Learner comment:
I do not like it. You waste valuable academic time, which my parents are paying for. We wasted time with senseless group debates. Just give us our books and let us learn.
Remark: This was one of the lowest achievers in the post-test. This learner begs for direct guidance and structure. He felt very lost in the less-structured PBL environment and consequently did not like the PBL experience. He seems to attribute his dislike to the fact that learners had to work co-operatively, rather than to the fact that learning was organized around problems.

(58%) Learner comment:
I think it is very nice and I enjoy it to do things on my own every now and then. One do [sic] *not only sit on your chair and write frantically like a zombie. I enjoy it.*

(69%) Learner comment:
I really enjoy these hands-on ... projects. It places science in a new, different light.

(72%) Learner comment:
The project was interesting. It was something new. You do not have to learn everything like a parrot. It is nice to do things and practical work on your own.
Remark: This learner who scored above the post-test average feels empowered by the fact that she could work on her own and not in a prescriptive, parrot-like fashion.

Discussion of results

Knowledge acquisition

Part of the rationale for implementing PBL in teaching is to overcome the gap between knowledge acquisition and the ability to use this knowledge (Everwijn, Bomers & Knubben, 1993:425). This could imply that some of the content topics in a regular syllabus need to be reconsidered to make space for the higher cognitive processes involved in solving a problem, which usually uses more time than merely covering topics. This study challenged the assumption that learners who have been taught through problem-based learning will acquire less content knowledge than their counterparts who were taught through direct, lecture-based strategies. Results showed that this particular cohort of Grade 10 science learners were not inferior to their lecture-taught counterparts with regard to knowledge acquisition. The per question analysis indicated that control group learners achieved significantly higher on selected cognitive type questions on a lower level, whilst experimental group learners achieved significantly higher on selected cognitive type questions on a higher level. In all the remaining questions there were no significant differences between the achievement of experimental and control groups.

This result is in line with research findings by Gallagher & Stepien (1996:257). In their study they compared high school learners' history scores on a multiple-choice standardised test (National Assessment of Educational Progress History Test) after traditional and problem-based teaching strategies were used. In their study, 50% of the school year was devoted to PBL, where there was no direct instruction of content to be 'covered' either before, during or after the problem-based intervention. To minimise the potential for traditional learning they also did not prescribe any textbook readings. The statistical evidence provided showed that in their case, the learners in the PBL course retained an equivalent amount of factual information to the learners subjected to conventional teaching strategies. It seems that both studies support the notion that teaching for depth of understanding also facilitates retention of facts. In another of the existing studies the Harvard Social Studies Project obtained results supporting the principle that higher order thinking induced by PBL provided an avenue to factual, content learning (Olivier & Shaver, 1963).

Reporting on research findings in PBL without looking at similar studies in the medical field where extensive work has been done in this regard, would not be complete. One study by Baca, Mennin, Kaufman & Moore-West (1990) found that medical learners in traditional and PBL curriculums attained equivalent scores in their clinical blocks during the last two years of medical school. In a similar study comparing McMaster University, which followed a PBL curriculum, and the traditional McGill University medical students, the PBL learners were found to hypothesise more, but they arrived at the correct diagnosis less often than the non-PBL learners (Patel, Groen & Norman, 1991). In a study of medical interns who were assessed by their supervisors, it was determined that the majority of the PBL graduates were graded "above average" in four clinical subjects but below average in knowledge of anatomy. In defence of the PBL strategy, Barrows & Tamlyn (1980) give a perspective on this debate that will serve as a conclusion for now to a discourse that will continue for as long as different strategies for teaching and learning exist. They say that medical learners often complete training by passing all the knowledge exams, but still do not know how to practice medicine effectively. In support of their view that knowledge that is not used is not well retained anyhow, they cite Miller's (1962) finding that before students graduate, they typically forget most of what they had learnt in their first-year anatomy and biochemistry courses.

Attitude towards PBL

The learners' experiences of PBL reflect varying attitudes, some negative and the majority (75.5%) more positive. The Fisher's Exact Two Tail Test indicated that a significant number of above-average achievers enjoyed PBL. A possible reason for this result may be ascribed to the fact that above-average achievers "exhibit high independence in learning and are better off in low-structured situations in which they can exercise their own initiative", while some low achieving learners often lack "the inner controls necessary for self-discipline and the cognitive skills necessary for independent learning" (Ornstein & Hunkins, 1993:8). These learners need and are more comfortable in highly structured environments. Ross & Kyle (1987) claim that direct instruction is one of the most effective strategies for teaching explicit concepts and skills to low-achieving learners, and in the present study, several low achievers actually expressed their preference for direct instruction over PBL. In this study 18 of the 34 below-average learners did not enjoy PBL at all, while 16 did. One below-average achiever made it clear that she enjoyed working on her own and that it was empowering not to be treated like a "zombie".

However, the fact that above average achievers significantly enjoyed learning through PBL does not mean that lower achievers should not be challenged and empowered to develop the necessary skills for functioning responsibly and independently in an ill-structured learning environment. On the contrary, life outside the classroom is complex and often threatening, whether learners prefer it or not. Real-life demands will not highlight the essence of a problem and provide the recipes to be used for solving it. Teachers and mentors will not always be there to provide direct instruction, the next steps or a structured, safe environment, even though learners might prefer it that way. The purpose of transformational OBE and the South African critical outcomes are geared towards preparing learners to perform complex real-life roles and to make them flexible life-long learners.

Conclusion

In conclusion it can be said that, within the framework of transformational outcomes-based education and the thrust towards greater learner-centered pedagogy, PBL should, at the very least, be considered a useful addition to the variety of existing teaching strategies that attempt to involve learners more in their own learning. It should be borne in mind, however, that trepidation towards self-directed learning takes time, since learners are purposefully pushed out of their comfort zones in order to set in motion a self-sustainable process of growth towards life-long learning.

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