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ORIGINAL ARTICLE

Enhancing Grade 10 Physical Sciences Teachers' Self-Directedness in Implementing Blended Problem-Based Learning

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ABSTRACT

The concept of self-directedness is a missing link in South African science classrooms, and as a result, science teachers are often not self-directed in employing innovative teaching and learning strategies such as blended problem-based learning (BPBL) that might enhance self-directed learning. The literature is replete with studies showing that science teachers in the United States, Indonesia, and South Africa, to name a few, lack the necessary technological skills to utilize simulations in the teaching and learning of physical sciences. This intervention-based explanatory mixed methods study was conducted in one of the nine education provinces of South Africa. Quantitative data were generated using a self-directed learning instrument (SDLI), the Physics Education Technology interactive simulations questionnaire, and a PBL questionnaire. Forty participants were sampled using both cluster and systematic random sampling techniques. Qualitative data were generated through a BPBL scenario, a reflective portfolio, and semi-structured interviews with two purposively selected participants. The quantitative data were analyzed using descriptive and parametric statistics. The reflective portfolio was analyzed using performance standards scoring rubric adopted from Smith et al. (2001). The BPBL Scenario Evaluation Schedule and interviews were analyzed using Saldaña's (2013) code-to-theory analytical model. It was concluded that there was a significant difference in participants' perceptions of PBL, self-directedness, and interactive simulations after attending a teacher professional development intervention (TPDI) and implementing BPBL. The findings show that the utilization of interactive simulations and PBL in physical sciences classrooms was unknown to teachers – suggesting that teachers were not self-directed in implementing BPBL. This study presents a model for designing BPBL activities and an evaluation schedule for assessing those activities for self-directedness in educational practices.

KEY WORDS: Blended problem-based learning; PhET interactive simulations; physical sciences teachers; self-directed learning; self-directedness

INTRODUCTION

Self-directedness is essential for the 21st century (Guglielmino, 2013) and is expected from professionals (Ahmad et al., 2019), including physical science teachers. Unfortunately, the concept of self-directedness is not well known to some teachers (Sebotsa et al., 2019), may be relatively new to some teachers (Lai et al., 2013), but it has been shown that through collaboration in an intervention, teachers may employ innovative teaching and learning strategies (Zonoubi et al., 2017) such as blended problem-based learning (BPBL). Self-directedness is a work-related learning process about adaptation to steering and taking responsibility to choose and implement appropriate teaching-learning strategies (Raemdonck et al., 2017; Verster et al., 2018). Self-directedness is integral to self-directed learning (SDL) (Du Toit-Brits, 2019; Raemdonck et al., 2017). SDL is defined as:

> A process in which individuals take the initiative, with or without the help of others, in diagnosing their own learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes. (Knowles, 1975, p. 18)

"SDL is recognized as a crucial aspect in the context of education for the 21st century" (Van Zyl and Mentz, 2019, p. 70). Self-directedness has three cornerstones: Skills, motivation, and self-belief (Gavriel, 2015). Teachers' self-directedness in teaching may result in the improvement of their own pedagogical skills (Golightly, 2019; Kramarski and Michalsky, 2009) and long-term career success (Seibert et al., 2001). In this study, pedagogical skills refer to designing and implementing BPBL for successful teaching and learning of a physical sciences topic. Designing BPBL for classroom implementation is a challenging process and requires a new set of knowledge, skills, and attitudes (An, 2013).

BPBL involves a teaching and learning pedagogy that combines blended learning and PBL strategies. Such a blended learning strategy refers to the incorporation of technology to enhance face-to-face teaching and learning in a classroom

Science Education International
33(4), 427-437
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(Porter et al., 2014). According to Rasheed et al. (2020), "blended learning is considered the most effective and most popular mode of instruction adopted by educational institutions due to its perceived effectiveness in providing flexible, timely, and continuous learning" (p. 1). Teaching and learning around the world has been dramatically changed and enhanced through the utilization of technology (Jaleel and Om, 2017), which is growing rapidly and can only be ignored to the peril of teachers. Suryani et al. (2021) call this a digital era that compels teachers to utilize technology in their classrooms, regardless of their readiness. However, most science teachers in the United States (Wang et al., 2014), Indonesia (Chai et al., 2020), and South Africa (Ogegbo et al., 2019) lack the necessary technological skills to utilize simulations in the teaching and learning of science (physical sciences in the South African context). Science teachers' ability to utilize information communication and technology (ICT) resources could promote motivation, creativity, and self-confidence (Roblyer and Doering, 2013; Shelly et al., 2010). This may include identifying and/or modifying available resources for utilization, such as interactive simulations to achieve learning goals (Warburton and Volet, 2012). In this study, Physics Education Technology (PhET) interactive simulations constituted a blended learning aspect.

PhET interactive simulations are a virtual learning media platform that is used to teach and learn abstract concepts in biology, mathematics, physics, and chemistry (Prima et al., 2018; Siswoyo and Muliyati, 2021). "PhET interactive simulations have been extensively tested and evaluated to ensure educational effectiveness, moreover, they are written in Java, Flash, or HTML5, and can be run online or downloaded to a computer" (Correia et al., 2019, p. 197). PhET interactive simulations software can be accessed on the internet at no cost (http://phet.colorado.edu). Once downloaded, PhET interactive simulations software can be used without the internet (Putranta and Wilujeng, 2019). Thus, PhET interactive simulations were partnered with PBL to design BPBL.

PBL is "a teaching approach that is initially aimed at activating learners' prior knowledge, facilitating critical analysis of [scientific] arguments, and promoting deep understanding of the content" (Loyens et al., 2015, p. 35). As a teaching approach, PBL could help science learners to recognize that content taught in the classroom is not isolated from context because PBL "aims to develop problem-solving skills through a self-directed learning as a life time habit and team work skills" (Ali, 2019, p. 73). In other words, PBL is an approach that could set the stage and prepare for future learning. The introduction of an ill-structured real-life problem of PBL makes it a significant approach – for example, in a physical sciences classroom, it allows learners to be involved and participate rather than silently learning facts from the teacher and a few active learners. "In the PBL process, an ill-structured, real-world problem (one to which there are many possible solutions) is presented to the students first" (Petersen et al., 2019, p. 154). In PBL, learners work together to plan and discuss the solutions through a seven-step method, namely, (1) defining concepts in the problem; (2) delineating and defining the problem; (3) analyzing the problem; (4) looking for explanations; (5) formulating the learning objectives; (6) searching additional information; and (7) preparing a report that provides a solution (Bilbao et al., 2018).

The South African Context

In South Africa, physical science is a secondary school subject that learners may choose from Grade 10 to 12. Both learners and teachers generally perceive it as a difficult subject (Hlabane, 2016). According to the Department of Basic Education (DBE) (2011), "Physical Sciences investigate physical and chemical phenomena. This is done through scientific inquiry, application of scientific models, theories, and laws to explain and predict events in the physical environment" (p. 8). Physical science is a combination of two discrete disciplines – that is, physics and chemistry. According to Kawedhar et al. (2019), chemistry is viewed as abstract. The present study focused on "Three States of Matter (TSM)," a topic in the chemistry component of the subject. It is necessary to mention that this topic is done in primary school in the Grade 4 subject called natural sciences. However, this topic is still problematic in Grade 10, since many primary school teachers are reluctant to teach science (James et al., 2017; Southerland et al., 2011) and some have not been trained to teach the subject (Bantwini, 2017). In some instances, science subjects in secondary schools, including Grade 10 physical sciences, are taught by unqualified science graduates (Pitjeng-Mosabala and Rollnick, 2018). The latter may be ascribed to various reasons, including a lack of qualified physical sciences teachers in the country. Pitjeng-Mosabala and Rollnick (2018) argued that such teachers lack content knowledge and/or pedagogical content knowledge to effectively teach the particulate nature of matter – a concept underpinning TSM. TSM refers to gas, liquid, and solid states as a result of thermal and electrostatic forces between and in molecules (Kapoor, 2019; Nuić and Glažar, 2020). According to Sebatana and Dudu (2022), TSM is a fundamental concept in science as a whole and in chemistry in particular. The teaching and learning of TSM presents multiple teaching and learning challenges (Harrison and Treagust, 2002; Kirbulut and Beeth, 2013).

Related Work

It is essential to mention that there is a dearth in the literature focusing on enhancing science teachers' self-directedness in designing BPBL for implementation (De Beer and Gravett, 2016). In the Netherlands, Louws et al. (2017) examined teachers' SDL and teaching experiences. The results of their study showed that teachers preferences were higher for the subject matter-specific domains, using technological tools, experimenting, and learning from reflection in practice and collaboration. In Turkey, Dogan (2017) presented her experiences of BPBL in teaching science aimed at improving pre-service science teachers' scientific inquiry views. Dogan found that, when utilizing BPBL, teachers overcame initial barriers to preparing lesson plans for teaching science and scientific inquiry. A Malaysian study by Nasri (2017)

Science Education International
33(4), 427-437
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investigated teachers' perceptions of their SDL and the findings show that teachers embraced the concept of learning together, "which emphasizes the recognition of learners as copartners in learning who share equal responsibilities in ensuring successful learning" (p. 169) and the role of ensuring that teaching and learning strategies they utilize "are suitable for the creation of a lively and interactive learning environment" (p. 169). Similar findings were reached in a study conducted by Shaalan (2019) in Saudi universities.

A quantitative study in North Carolina, United States, by Lee and Blanchard (2019) explored middle and high school teachers' perceptions of utilizing PBL. These researchers generated data by means of a questionnaire that was adapted for this study. The results showed that two groups were designated as "PBL" (n = 126; 81%) and "non-PBL" (n = 30; 24%) based on whether they had previous experience of implementing PBL. Most of the teachers (90.4%) had sufficient preparation for teaching with PBL. The Wilcoxon signed-rank test – the non-parametric equivalent of the paired samples t-test – was conducted for both PBL and non-PBL groups and the results showed that there were highly significant differences between the PBL and non-PBL groups in implementing PBL.

In a South African study, Mulaudzi (2021) investigated the implementation of hybrid problem-based learning (hPBL) to foster pre-service technology teachers' SDL competencies. One of the data generation instruments employed by Mulaudzi was the Self-Directed Learning Instrument (SDLI) adopted from Cheng et al. (2010), the same instrument used in this study. Mulaudzi found a Cronbach's alpha score of 0.807. The results of Mulaudzi's study showed that the implementation of hPBL, where real-life problems are used in a technology module, positively influenced pre-service teachers' perceptions of their SDL abilities. In a pilot study, Kriek and Stols (2010) examined the influence of the beliefs of Grade 10−12 physical science teachers on their intended and actual usage of PhET interactive simulations in their classrooms. Kriek and Stols used a PhET questionnaire that was also adapted for the present study. Using regression and factor analyses, the results of their study showed that beliefs about the perceived usefulness and the pedagogical compatibility of PhET have a significant effect on teachers' attitudes toward the use of the simulations in their classrooms.

Study Purpose

This study focused on physical science teachers' self-directedness to implement BPBL in the teaching and learning of TSM. To enhance self-directedness, teachers need to participate in a teacher professional development intervention (TPDI) (Beckers et al., 2016). Therefore, in this study, a 3-day TPDI was designed and conducted so as to enhance physical science teachers' self-directedness in utilizing BPBL in the teaching and learning of TSM. The following research question guided this study: How can physical sciences teachers' self-directedness in implementing blended problem-based learning be enhanced in a teacher professional development intervention?

THEORETICAL FRAMEWORK

The theoretical framework that underpinned this study is Kolb's (1984) experiential learning model (Figure 1), which illustrates the learning cycle that is activated through experiential learning.

Kolb's experiential learning model shows that effective learning takes place when a learner progresses through a cycle of four stages: (1) Having concrete experience; (2) reflective observation of that experience; (3) abstract conceptualization; and (4) active experimentation (Kolb, 1984). In the present study, the aforementioned cycle began with the teacher, as a learner, learning the process of designing BPBL related to a chemistry topic, TSM. This experience may result in a teacher reflecting on the observation and subsequently consulting the physical sciences curriculum as stipulated by the department of basic education. Reflective observation may then lead to conceptualization of designing BPBL wherein self-directedness is enhanced. Once a teacher is self-directed to design BPBL, they may proceed to implementing BPBL in a teaching and learning situation.

METHODOLOGY

Research Design, Context, and Participants

This intervention-based study followed an explanatory mixed methods research design. The study was conducted in the North-West province, one of the nine education provinces of South Africa. This province is divided into four education districts. For the quantitative phase of this study, the cluster sampling technique was employed – those districts were taken as clusters. Systematic random sampling was then utilized to sample 10 physical sciences teacher from each cluster. A total of 40 teacher participants were sampled. For ethical considerations, ethical clearances were obtained from:

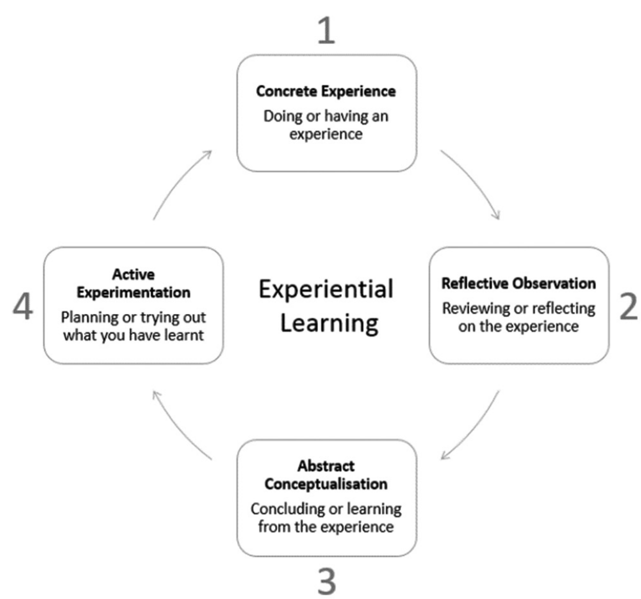

Figure 1: Kolb's (1984) experiential learning model

Science Education International
33(4), 427-437
https://doi.org/10.33828/sei.v33.i4.11

(1) The institution where researchers work; (2) the North-West Department of Education; and (3) secondary schools where teacher-participants were based before this study commenced. Participants provided their informed consent after they were informed of the purpose of this study and data generation methods followed. Participants were also informed that participation was voluntary, and they confirmed in the affirmative. In addition, participants were informed that they could withdraw from this study at any time. For the qualitative phase, purposive sampling was then used to select two participants from each of the 10 participants in each cluster, resulting in eight participants. It is important to mention that this study emerges from a larger doctoral research project. Therefore, for the present study, only two participants were selected. Both participants were male and were given pseudonyms – Radon (35 years old) and Chad (29 years old). Radon held a Post-Graduate Certificate in Education (PGCE), and Chad held a Bachelor of Education (B.Ed) degree. At the time of this study (October 2021), their teaching experiences were as follows: Radon had 8 years' work experience and Chad had 6.

Data Generation Instruments

The self-directed learning instrument (SDLI) adopted from Cheng et al. (2010), the PhET interactive simulations questionnaire adapted from Kriek and Stols (2010), and the PBL questionnaire adapted from Lao (2016) were utilized to generate quantitative data. Qualitative data were generated using the 3C3R [Core components (3C) – content, context, and connection; processing components (3R) – namely, researching, reasoning, and reflecting] PBL Scenario Evaluation Schedule developed and completed by the authors, reflective portfolios, and semi-structured interviews.

The SDLI consisted of 20 statements grouped into four domains – learning motivation, planning and implementing, self-monitoring, and interpersonal communication – and these were measured on a 5-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). The adapted PhET interactive simulations questionnaire contained 32 questions. This instrument's item was measured on various Likert scales for all the questions – for example, questions varying from "extremely unlikely to extremely likely" or "definitely false to definitely true." Examples of items from SDLI are "I would be able to use PhET in my classroom," and "[u]sing PhET enhances my effectiveness in the classroom." The PBL questionnaire was divided into three sections: Section A – Background Information; Section B1 – Teachers' beliefs about PBL and its value to students; and Section B2 – Expectancy of success and self-determination for practicing PBL. Section B1 consisted of 15 questions for the pre-TPDI. Section B2 consisted of 24 questions for post-TPDI. Both sections B1 and B2 consisted of a 6-point Likert scale: Strongly disagree, disagree, somewhat disagree, somewhat agree, agree, and strongly agree. Examples of items were "[i]n PBL students engage in issues relevant to their lives/communities" and "I do not feel competent to teach with a PBL approach."

The 3C3R PBL Scenario Evaluation Schedule measured the extent to which components of the second generation of the 3C3R PBL problem design model by Hung (2019) (Figure 2) were adhered to and/or shown using the Positive and Negative Affect Scale developed by Simmons and Lehmann (2012). The ratings on this scale are as follows: (1) Not at all; (2) a little; (3) moderately; (4) quite a bit; and (5) extremely. The reflective portfolio was compiled during BPBL implementation while teaching TSM. The reflective portfolio included various documents such as lesson plan(s), learners' completed assignments, and the teacher's critical reflection. The interviews further consisted of five semi-structured questions, for example, "How did the intervention help you design BPBL?" and "How can you describe BPBL implementation while teaching TSM?"

Research Methods: The Teacher Professional Development Intervention (TPDI)

An explicit 3-day TPDI was conducted for physical sciences teacher participants in this study from January 19 to 21, 2022. The quantitative instruments mentioned in the preceding sections were used to assess the teacher participants' perceptions of each construct (i.e., SDL, PhET interactive simulations, and PBL). These were administered 6 weeks before (November 2021) and after (March 2022) the TPDI. During the TPDI, each participant was provided with a laptop. Furthermore, each participant was provided with tablets for each learner in their Grade 10 physical sciences class. The TPDI consisted of blended learning (PhET interactive simulations) and PBL workshops that lasted between 7 and 8 h per day. The workshops focused on designing teaching and learning activities related to TSM and incorporated the utilization of PhET interactive simulations using Hung's (2019) second generation of the 3C3R PBL problem design model (Figure 2).

The second generation of the 3C3R PBL problem design model comprises three classes, namely, core, processing, and enhancing components. Core components (3C) include

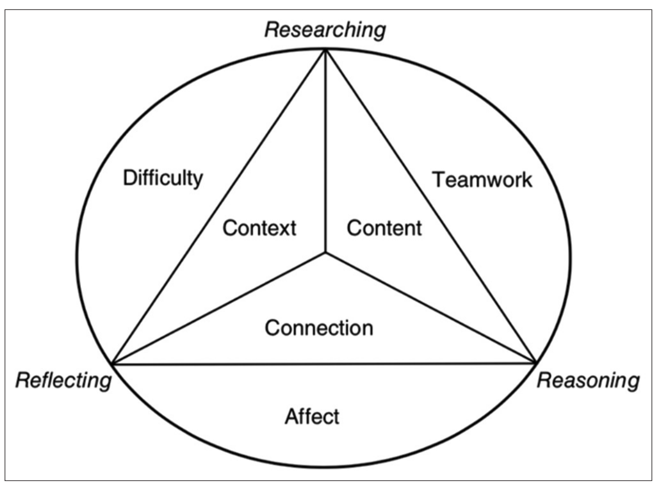

Figure 2: The second generation of the 3C3R PBL Problem Design Model (Hung, 2019, p. 251)

Science Education International
33(4), 427-437
https://doi.org/10.33828/sei.v33.i4.11

content, context, and connection. Processing components (3R) – namely, researching, reasoning, and reflecting – relate to the learners' learning processes and problem-solving skills. Enhancing components comprise affect, difficulty, and teamwork. According to Hung (2019), enhancing components may potentially influence individuals' motivation, engagement, SDL, and/or shared learning. Textbox 1 outlines one PBL scenario formulated by teachers, which they also implemented in their teaching of TSM.

The North-West province, especially the educational district where the participants of this study taught at the time of this study, has experienced an increase in service delivery protests (Klinck and Swanepoel, 2019). This study TPDI was guided by a competence-based model of progression (Figure 3) as outlined by Jones et al. (2002).

The progression model shows that, in the Foundation Phase, the teacher (as a learner) is not self-directed and is unable to design blended problem-based learning (BPBL). From the Foundation Phase, a teacher experiences learning in which skills, abilities, and knowledge of designing PBL activities are developed. Thereafter, technology tools are integrated, allowing the teacher to acquire skills, abilities, and knowledge. At this stage, the teacher is expected to cope with the new knowledge and to apply it in new situations. Finally, the teacher demonstrates acquired skills, thus showing self-directedness. Therefore, the teacher is expected to "be aware of the need to dissect their own actions in a conscious manner that they have probably not attempted for a while" (Gavriel, 2015, p. 149).

Textbox 1: Problem-based learning scenario related to TSM

"The district municipality is failing to provide service delivery in the Saratoga township. There has been a sewage blockage which results in sewage water running down the streets. The people in Saratoga are always complaining about the smell from this sewage. Kim is your friend and does not take physical sciences subject. She tells you that the smell of the sewage seems to be stronger during the night and weak during the day but she does not know why. Kim asks you, as a science learner, to explain what could be the reason behind the change of smell, and how she could solve this problem.

During a physical sciences lesson, ask learners in your group to help you with explanations [sic] and solution and/or recommendations for Kim."

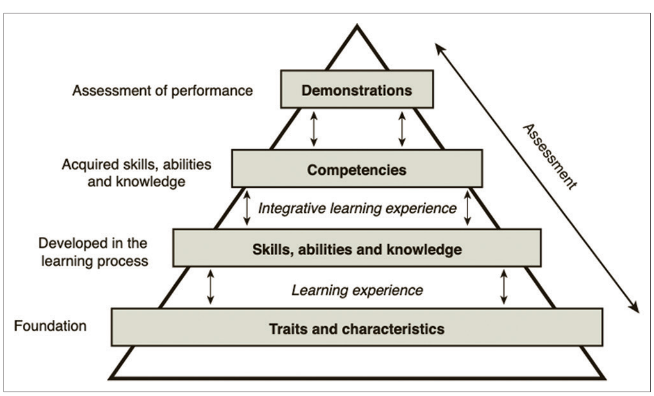

Figure 3: A competence-based model of progression outlined by Jones et al. (2002, p. 8)

Data Analyses

Quantitative data were analyzed using descriptive and parametric statistics. The Statistical Package for the Social Sciences (SPSS, Version 21.0; IBM, 2022) software was used for data analysis. The Shapiro–Wilk and Wilcoxon signed-rank tests were employed. The reflective portfolio was analyzed using the Interstate New Teacher Assessment and Support Consortium (INTASC) performance standards scoring rubric adopted from Smith et al. (2001). This rubric has 10 INTASC principles that serve as the basis of evaluation using the following four scoring criteria: 4 = Clear, convincing, and consistent evidence; 3 = Clear evidence; 2 = Limited evidence; and 1 = No evidence. Overall evaluation of the portfolio is as follows: 10–17.5 = No evidence; 17.5–25 = Limited evidence; 25–32.5 = Clear evidence; and 32.5–40 = Clear, convincing, and consistent evidence. The 3C3R PBL Scenario Evaluation Schedule and interviews were analyzed using Saldaña's (2013) code-to-theory analytical model to identify 19 codes that were later grouped into nine categories to generate themes. The themes generated for this study are as follows: Assessment performance during active experimentation and competence during concrete experience.

DATA PRESENTATION AND DISCUSSION

Quantitative Data

Problem-based learning questionnaire results

The participants' results regarding qualifications are illustrated in Figure 4.

As shown in Figure 4, more than 50% (n = 23) of the teacher-participants held a B.Ed. degree, a quarter (25%; n = 10) held a PGCE, 15% possessed a B.Ed. Honors degree, and about 2% (n = 1) held a Master of Education (M.Ed.) degree. Unlike Lee and Blanchard (2019), whose participants were any secondary and high school teachers, this study focused specifically on physical science (secondary school) teachers teaching Grade 10 level. It was deemed necessary to investigate teacher participants' qualifications, since physical science is known to be taught by unqualified teachers, as highlighted by other researchers (Bantwini, 2017; James et al., 2017; Pitjeng-Mosabala and Rollnick, 2018; Southerland et al., 2011). The

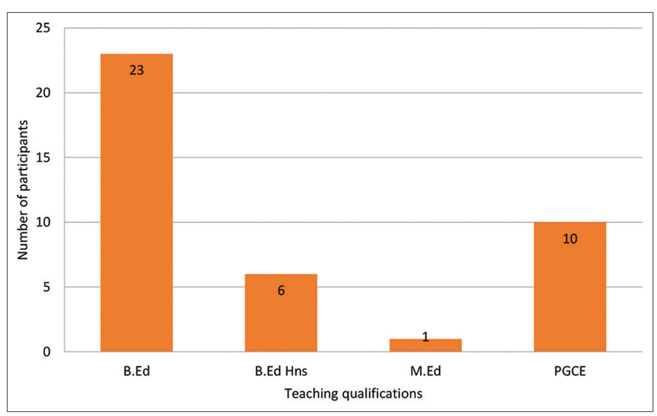

Figure 4: Teacher-participants' qualifications

Science Education International
33(4), 427-437
https://doi.org/10.33828/sei.v33.i4.11

results showed that all participants in this study were qualified science teachers, with only 25% whose first qualifications were not in teaching, therefore held a PGCE. Participants' teaching experience results are outlined in Figure 5.

This study's results (Figure 5) show that more than 50% (n = 23) of the teacher-participants had 11–15 years teaching experience; more than 25% (n = 11) had more than 15 years teaching experience; about 12% had 6 to 10 years; and only about 2% (n = 1) had less than 5 years. These results show that most of the participants in this study had considerable teaching experience and might have used various teaching and learning strategies in their careers. In establishing the number of teachers who had received PBL training previously before participating in this study, results are depicted in Figure 6.

The results of this study show that only 37% (n = 15) had received PBL training, while 63% (n = 25) had not received PBL training before attending the TPDI. It was found that only 37.5% of participants had experience of teaching through PBL teaching and learning strategy. The rest of the teacher participants (63%) indicated that they did not have experience of teaching through PBL: 68% did not have the required professional training for PBL; 24% did not believe that they could successfully implement PBL; 4% did not have support from their school administrators; and the remaining 4% were not interested. Almost all (98%; n = 39) of the teachers said that they would like to teach using a PBL strategy, while just 2% (n = 1) said that they would not. These results contradict those by Lee and Blanchard (2019) who found that 81% of the teachers had experience of implementing PBL, since most of the teachers (63%) did not have experience of implementing PBL. Furthermore, while 90% of the teachers in the study by Lee and Blanchard indicated that they had training in PBL, 68% of the teachers in this study had never received PBL training. Juxtaposing results of this study with those of Lee and Blanchard (2019), it can be argued that the implementation of PBL is prevalent in the United States secondary and high schools but not in the South African secondary schools, particularly in physical sciences classrooms.

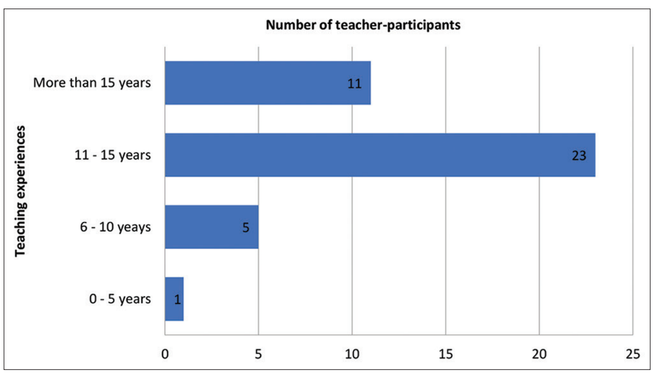

Figure 5: Participants' teaching experiences

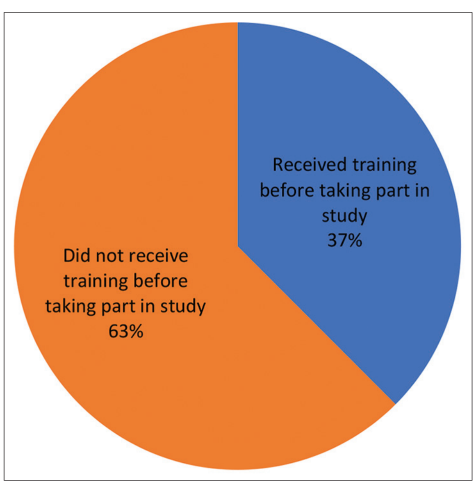

Figure 6: Participants who received PBL training before taking part in this study

The reliability of the instrument was examined using Cronbach's coefficient measure of reliability. The result confirm that the Cronbach alpha value is approximately 0.60; thus, the results of this instrument were reliable. However, the instrument can be improved for robust reliability. The Shapiro–Wilk test was used to determine analysis carried out. Table 1 outlines the Shapiro–Wilk test results.

The p-values for the pre- and post-TPDI results were 0.645 and 0.364. These p-values suggest that the results were not statistically significant since they followed a normal distribution. Therefore, a paired sample t-test was employed. Results for a paired sample t-test are presented in Table 2.

Table 2 shows that perceptions of teacher participants were statistically significant after attending the TPDI, since the p-value was 0.001. The null hypothesis that the mean of differences between the pre- and post-TPDI results equals 0 was rejected. Hence, it was concluded that there was a significant difference in participants' perceptions of PBL after attending the TPDI and implementing BPBL. These findings concur with those found by Lee and Blanchard (2019). This is an interesting finding given that the instrument in question was adapted and used in a different context for the present study.

PhET interactive simulations questionnaire results

Background data of this instrument ascertained the status of teaching and learning resources and facilities in each teacher-participant's secondary school. The results are shown in Figure 7.

The results show that more than half (55%; n = 22) of the teachers indicated that their school resources and facilities were average; 1 in every 5 (20%; n = 8) said that their school

Table 1: Problem-based learning test of normality results

Pairs	Kolmogorov–Smirnov[a]			Shapiro–Wilk		
	Statistic	df	Significant	Statistic	df	Significant
Pre-TPD	0.091	40	0.200*	0.979	40	0.645
Post-TPD	0.082	40	0.200*	0.970	40	0.364

*This is a lower bound of the true significance, [a]Lilliefors significance correction. TPD: Teacher professional development

Science Education International
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Table 2: Paired samples test results

Pairs	Mean	SD	SEM	95% CI of the difference		t	df	Significant (two tailed)
Pair 1				Lower	Upper			
Pre-TPD-post-TPD	0.32479	0.55892	0.08837	0.14604	0.50354	3.675	39	0.001

CI: Confidence interval, SD: Standard deviation, SEM: Standard error of mean, TPD: Teacher professional development

resources and facilities were better than average. Moreover, 18% (n = 7) of participants indicated that their school resources and facilities were below average, while 7% (n = 3) agreed that their school resources and facilities were in a poor condition. It is worth noting that the participants were asked about the state of technological resources in their schools to identify if teachers needed any. These results show that technological resources are average and better than average for most secondary schools in the North-West province. These results verify that resources are not a problem for employing blended learning – particularly the utilization of PhET interactive simulation. However, in this case, as mentioned in the methodology section, participants were provided with technological resources to ensure the success of this study.

The split-half procedure for reliability was conducted for the PhET Interactive Simulations Questionnaire instrument. Table 3 shows the results.

As shown in Table 3, variables from this instrument were divided into two equal parts of 16 each. For the pre-TPDI, Cronbach's alpha for part 1 was 0.946, while that of part 2 was 0.918. These values reflect a high internal consistency. To check the reliability between the two parts, the Spearman–Brown correlation coefficient for equal length was adopted, and its value was 0.953. This demonstrates a strong positive correlation between the two parts. For the post-TPDI, Cronbach's alpha for part 1 and part 2 was 0.887 and 0.883, respectively. These values show a high internal consistency. To check the whole instrument with regards reliability between the two parts, the Spearman–Brown correlation coefficient for equal length was adopted, and its value was 0.855. This also reflects a strong positive correlation between the two parts. Cronbach's alpha was also employed to check the reliability of results from this instrument. The results showed that the Cronbach alpha value for the pre- and post-TPDI results was 0.965 and 0.931, respectively, which confirmed that the results were highly reliable.

The Shapiro–Wilk test was used to determine analysis. Table 4 shows the test of normality results.

ρ-values for the variables pre- and post-TPDI were 0.002 and 0.000, respectively. These results were statistically significant, thus, the null hypothesis that they follow a normal distribution was rejected. Therefore, the Wilcoxon signed-rank test was conducted, and ρ= 0.000 was statistically significant. Thus, there was a significant difference in teacher participants' PhET perceptions after the TPDI. In their study, Kriek and Stols (2010) did not show Cronbach's alpha value for this instrument. Instead, they used regression and factor analyses; the results of

Table 3: Physics education technology reliability statistics

Reliability statistic	Pre-test	Post-test
Cronbach's alpha		
Part 1		
Value	0.946	0.887
Number of items	16[a]	16[a]
Part 2		
Value	0.918	0.883
Number of items	16[b]	16[b]
Total number of items	32	32
Correlation between forms	0.915	0.756
Spearman–Brown coefficient		
Equal length	0.956	0.861
Unequal length	0.956	0.861
Guttman split-half coefficient	0.953	0.855

[a]Q1, Q2, Q3, Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12, Q13, Q14, Q15, Q16, [b]the items are: Q17, Q18, Q19, Q20, Q21, Q22, Q23, Q24, Q25, Q26, Q27, Q28, Q29, Q30, Q31, Q32

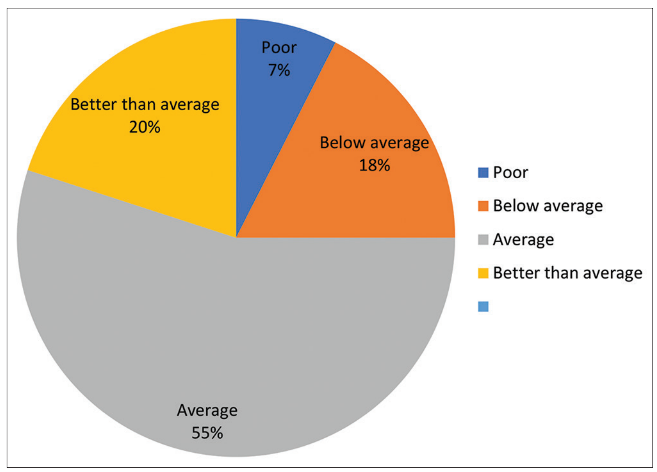

Figure 7: Status of teaching and learning resources and facilities in participants' secondary schools

their study showed that beliefs about the perceived usefulness and the pedagogical compatibility of PhET have a significant effect on teachers' attitudes toward the use of simulations in their classrooms. Arguably, these results by Kriek and Stols concur with those of the present study.

Self-directed learning instrument results

Cronbach's alpha was also employed to check the reliability of the instrument. The result shows that the Cronbach's alpha values for the pre- and post-TPDI results were 0.957 and 0.847, respectively, which confirmed that the instrument is highly reliable. In another study, Mulaudzi (2021) found a Cronbach's

Science Education International
33(4), 427-437
https://doi.org/10.33828/sei.v33.i4.11

alpha score of 0.807. It can be argued that the Cronbach alpha values for both studies are similar. In this study, the Shapiro–Wilk normality test was employed to determine the teacher participants' perceptions (Table 5).

ρ-values for the pre- and post-TPDI were 0.010 and 0.092, respectively. The pre-TPDI ρ-values were statistically significant, while the post-TPDI value was not. Therefore, the null hypothesis that the pre-TPDI results follow a normal distribution was rejected, while it was retained for the post-TPDI results. The normal Q–Q plots (Figure 8) also show outliers in the data, which confirmed the non-normality of the data.

To compare the pre- and post-TPDI results, the Wilcoxon signed-rank test was employed. The results produced $\rho = 0.002$, which is statistically significant. Therefore, the null hypothesis that the median of differences between the pre- and post-TPDI results equals 0 was rejected. Consequently, it was concluded that there was a significant difference in the participants' perceptions of their SDL abilities. The descriptive statistics also confirmed that the TPDI positively enhanced the teacher participants' SDL abilities, as the mean score of post-TPDI results was calculate at 88.73 – higher than the mean score of the pre-TPDI results, which was 80.88. This study's results corroborate those by Mulaudzi's study which showed that the implementation of hPBL, where real-life problems were used in a technology module, positively influenced pre-service teachers' perceptions of their SDL abilities.

Table 4: Physics education technology test of normality results

Pairs	Kolmogorov–Smirnov[a]			Shapiro–Wilk		
	Statistic	df	Significant	Statistic	df	Significant
Pre-PhET	0.195	40	0.001	0.898	40	0.002
Post-PhET	0.177	40	0.003	0.868	40	0.000

[a]Lilliefors significance correction. PhET: Physics education technology

Table 5: Self-directed learning test of normality results

Pairs	Kolmogorov–Smirnov[a]			Shapiro–Wilk		
	Statistic	df	Significant	Statistic	df	Significant
Pre-SDL	0.138	40	0.055	0.924	40	0.010
Post-SDL	0.125	40	0.114	0.952	40	0.092

[a]Lilliefors significance correction. SDL: Self-directed learning

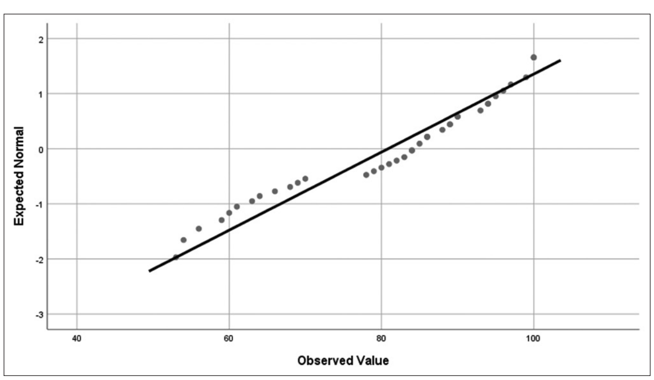

Figure 8: Normal Q–Q plots

Qualitative Data

This section presents the data according to generated themes.

Competence during concrete experience

Radon and Chad anticipated the designed BPBL to promote TSM constructs such as "diffusion, Brownian motion, and kinetic molecular theory." In evaluating the designed BPBL activity, findings show that it contained core (content, context, and connection) and enhancing components (affect, difficulty, and teamwork) that could be promoted "quite a bit." Regarding core components, the PBL scenario was to reflect profession-specific skills to "a little" extent. Regarding enhancing components, the PBL scenario was found to lack explicit roles that each learner must fulfill within a group. The PBL scenario was found to have the potential to promote process components "extremely." With regards process components, the PBL scenario was found to promote reasoning "extremely" more than anything else. It was found that PhET interactive simulations could be utilized for both teaching and learning of TSM constructs in the designed activities. These findings corroborate those of Louws et al. (2017), namely, that teachers learn from collaborating with each other. When asked "How did the intervention help you design BPBL?" Radon said the following:

> From the discussions we had there, I could design BPBL with the help of my learners and it reduces my workload. I had never used PhET interactive simulations or problem-based learning in chemistry. But I had used simulations when teaching electric circuits.

Responding to the same interview question, Chad's response was as follows:

> I think it was a good experience for me to learn about problem-based learning because it is better than the previous methods I was using. Another was the use of ICT skills; to use them in the classroom, in [a] controllable manner, and ensuring that the learners do what they are supposed to do so that they can benefit.

These findings show that the intervention enhanced the participants' skills to design BPBL. These findings also show that both Chad and Radon did not know about PBL. It is interesting that both participants were familiar with utilizing PhET interactive simulations for the physics but not the chemistry aspect. Another interesting finding was shared by Chad who stated that the intervention assisted him in utilizing PhET simulations in an effective manner. In line with the findings of this study, Louws et al.'s (2017) findings showed that science teachers prefer teaching science content using technological tools – thus, creating an effective interactive learning environment, as shown by Nasri (2017) and Shalaan (2019). Furthermore, the findings of this study corroborate those of Dogan (2017) who shows that designing activities for implementations helped teachers to prepare for the lesson thoroughly.

Science Education International
33(4), 427-437
https://doi.org/10.33828/sei.v33.i4.11

Assessment performance during active experimentation

The findings of this study show that both Radon and Chad were able to successfully implement BPBL in their physical science classrooms with their learners. Radon's reflective portfolio showed "clear, convincing, and consistent evidence" (96%) of successful BPBL implementation. Chad's reflective portfolio showed "clear evidence" (79%) of BPBL implementation in his classroom. These findings are highly satisfactory. After implementing BPBL in the teaching and learning of TSM, participants were asked, "How can you describe BPBL implementation while teaching TSM?" In this regard, Radon said:

> This was my first exposure to BPBL with my learners, and I think we did it great. During the workshop, we really thought that it is going to be demanding but it was not. I think implementing PBL and use of PhET simulations have really improved my relationship with my learners.

Chad's response was:

> I think because there are different types of learners in class, some are visual, some are auditory, some are kinesthetic, and some are social. So, using those PhET simulations together with PBL, I was able to engage all of them.

These findings show that both Radon and Chad were satisfied with their experience of implementing BPBL in their classes. One interesting finding was shared by Chad who stated that implementation of BPBL engages all learners in the class, as it accommodates various learning styles. These findings corroborate Louws et al.'s (2017) findings. Their findings verified that science teachers like experimenting new teaching and learning strategies. It interesting that findings of the present study and those of Louws et al. are in line with the last stage (i.e., active experimentation) of Kolb's (1984) experiential learning model, which was the theoretical framework that underpinned this study. Another interesting finding emerged from Radon's account: Implementing BPBL promotes the teacher-learner relationship. This finding concurs with findings by the previous scholars (Nasri, 2017; Shalaan, 2019) in pertinent related work that showed that teachers recognized "learners as copartners in learning who share equal responsibilities in ensuring successful learning."

CONCLUSIONS AND RECOMMENDATIONS

The results of this study illustrated a significant difference in physical sciences teacher-participants' perceptions of utilizing interactive simulations, PBL, and their SDL abilities after participating in a teacher professional development intervention and classroom implementation of blended problem-based learning. The findings of this study showed that, to enhance self-directedness in implementing BPBL in a professional development intervention, physical science teachers must be exposed to the full potential of interactive simulations, generation of BPBL activities, and management skills to implement BPBL in teaching and learning TSM. However, results of this study may not be generalized given the size of this study's sample. This study presents a model for designing BPBL activities and an evaluation schedule for assessing those activities for educational practice. The study recommends partnering of PhET interactive simulations and PBL when planning and designing teaching and learning activities for sciences teaching which might enhance teachers' self-directedness.

Ethical Statement

Ethical clearance for this study was approved by the North-West University, Faculty of Education Research Ethics Committee (Edu-REC) on June 24, 2021. This study was considered a "Low Risk." The ethics number for this study is NWU-01908-20-A2.

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