A Proposed Framework on Simulation-embedded Scaffolding of Problem-based Learning for Science Teachers

Judicial Sebatana[1], Aubrey Golightly[2]

North-West University, Self-Directed Learning, South Africa[1]
North-West University, Self-Directed Learning, South Africa[2]

Abstract

This study proposes a framework for the simulation-embedded scaffolding of problem-based learning (PBL) for science teachers' self-directedness in learning. The literature shows a lack of existing frameworks for science teachers to scaffold PBL in the classroom. Furthermore, science teachers, including those in South Africa, avoid implementing PBL in their classrooms. This is owing to various challenges, such as a lack of knowledge of and self-directedness in planning, designing and implementing PBL problems. The theoretical framework for this study was the zone of proximal teacher development (ZPTD), refined by Warford from Vygotsky's zone of proximal development (ZPD). The paper presents a framework for teachers' PBL and teaching self-directedness in teaching, namely Problem-based Learning and Teaching Self-directedness in Teaching (PBLT-SD). This intervention-based study followed a descriptive quantitative research design. Systematic random sampling, partnered with cluster sampling, was employed to sample 40 science teachers from a province in South Africa for an in-depth study. Three quantitative data generation instruments were used, namely a simulations questionnaire, a PBL questionnaire and a reflective portfolio. The results and findings of this study illustrated a significant difference in the science teacher participants' perceptions of using interactive simulations, PBL and their self-directedness in learning after participating in an intervention. The intervention consisted of a teacher professional development intervention and the classroom implementation of PBL, partnered with simulations, thus corresponding well with the theoretical framework of the study, namely ZPTD.

Keywords: *problem-based learning; science teachers; self-directedness*; *simulation-embedded scaffolding*

1. Introduction and Background

As educational reforms progress, there is a call to implement problem-based learning (PBL) in the teaching and learning of the STEAM subjects, namely science, technology, engineering, art and mathematics. This call is evident in various countries, such as Denmark [1, 2], South Africa [3, 4, 5] and the United States of America [6, 7]. Globally, education departments, including the Department of Basic Education in South Africa [8] recommends PBL as a learner-centred teaching and learning strategy for school sciences. PBL is an influential type of inquiry-based learning in which learners use an authentic problem as the context for an in-depth investigation of what they have to know [9]. PBL is a comprehensive learner-centred, group-based and problem-orientated teaching and learning strategy [10]. The term "problem-based learning" was initially coined for medical education [11]; however, in the past few decades, it has also become popular in teacher training and school education [12, 13, 14].

Unfortunately, science teachers around the world avoid implementing PBL in their classrooms owing to various challenges, such as a lack of knowledge and self-directedness in planning, designing and implementing PBL problems [15, 16, 17]. [18] outlines a systematic method specifically designed to guide instructional designers and educators to design effective PBL problems for all levels of learners, thereby strengthening the characteristics of PBL and alleviating issues of implementation. This systematic method is known as the 3C3R PBL Problem Design Model. More recently, Hung [19] modified this model to the Second Generation of the 3C3R PBL Problem Design Model. This model was adopted and used for this study. The Second Generation of the 3C3R PBL Problem Design Model consists of three classes of components, namely core, processing and enhancing components. The core components comprise content, context and connection (3C), which deal with the designing of the PBL problem. The processing components – researching, reasoning and reflecting (3R) – concern the learners' learning processes and problem-solving skills. The enhancing components are affect, difficulty and teamwork, which may influence an individual's motivation to learn, engagement in learning, self-directed learning and shared learning [19].

Self-directedness in teaching is a work-related learning process about adaptation to steering and taking responsibility to choose and implement appropriate teaching-learning strategies [20, 21]. This learning process is essential for the 21st century [22] and is expected of professionals [23], including science teachers. In other words, self-directedness is essential for the effective implementation of PBL partnered with simulations. Simulations use multimedia, such as sound, text and graphics, to bring about desired outcomes based on a specific real-life scenario. The use of simulations in a science classroom enhances learner engagement in the content they are learning [24]. As part of artificial intelligence, simulations make classrooms conducive to teaching and learning in various ways. With simulations, this is accomplished by providing instruction in mixed-ability classrooms, providing learners with detailed and timely feedback on their tasks, freeing teachers from the burden of possessing all knowledge and giving them more opportunities to facilitate and monitor learning [25]. Teacher scaffolding is important for learners' effective learning during teaching when simulations are embedded into PBL [26, 27]. Simulation-embedded scaffolding is a multiple-outcome narrative with standards-based information. It is designed to offer practice and decision-making opportunities, promote reflection and scaffold new ideas or cognitive artefacts [28]. Providing extra support to science teachers on the simulation-embedded scaffolding of PBL can promote self-directedness in teaching [14]. Therefore, a teacher professional intervention was conducted for science teachers. The Department of Basic Education needs to improve the teaching and learning of science curricula according to their contexts [29]; however, there is a lack of guidance (in the form of frameworks) on how it can be achieved.

1.2 Review of Related Studies

As in the current study, a Canadian study was conducted to explore designing and implementing PBL in the context of high school science [30]. While the current study was quantitative in nature, with 40 science teachers, the Canadian study was qualitative, with only one science teacher [30]. The documents they used for data generation are, to some extent, similar to the portfolio used in the current study. As in the current study, their first challenge was choosing a PBL problem that was aligned with the curriculum goals and learning outcomes. The findings of their study showed that as the participant commenced implementing PBL, she struggled with the PBL process and time management. In a study conducted in the United States of America [31], the challenges associated with PBL included a lack of PBL knowledge and experience, losing the focus and content of the subject, a lack of science-orientated material resources and instructional resources, demands with regard to aligning PBL activities with the standards of the subject and time constraints. A South African study [32] argues that the concept of being self-directed is not known to teachers and, as a result, teachers are often not self-directed in employing innovative teaching and learning strategies in their classrooms.

In the United States of America, a review study [33] was conducted to examine the implications of science inquiry tools for classroom teaching and learning practices. The findings of the review study were summarised in a technology-enhanced, inquiry-based science class framework. The framework shows that three interlinked dimensions are key to exploring the role of technologies. These dimensions are the macro-context, the teacher community and the micro-context. The macro-context involves systemic reform and educational standards; the teacher community is the physical or virtual context, where teachers share expertise and mentor one another; and the micro-context is the classroom context, where learning and teaching occur. However, this is only a pedagogical framework for classroom implementation and is not specific to a particular teaching and learning strategy or technology tools. In the Netherlands, 309 teachers' self-directed learning was investigated relating to their teaching experience [34]. It was found that teachers strongly preferred being self-directed in domains specific to subject matter, digital devices and multimedia.

A study conducted in Indonesia was aimed at using simulation activities during the implementation of PBL, dealing with work and energy concepts, to promote critical thinking skills [35]. The effectiveness of the process was observed and the results of the study showed success in pairing simulations with PBL. In other words, simulations are effective learning mediums for understanding abstract concepts, such as work and energy, and improve the critical thinking skills of learners. Another American study [27] examined how 163 Grade 9 biology learners' academic achievement and group performance related to their perceptions of the usefulness of hard scaffolding, peer scaffolds and teacher scaffolds in inquiry-based learning activities. The study proposed a framework based on the implementation of inquiry-based learning, rather than PBL [27]. Therefore, the framework does not show support for enhancing teachers' knowledge – an aspect that the current study focused upon, namely promoting teachers' self-directedness in teaching. The theoretical framework that equally guided the development of the framework proposed in this study is delved into next.

1.3 Theoretical Framework

The theoretical framework for this study was the zone of proximal teacher development (ZPTD) refined by Warford [36] from Vygotsky's [37] zone of proximal development (ZPD). The ZPTD refers to teacher development where learning and professional development take place in four eminent stages. The ZPD is one of Vygotsky's best-known ideas and is embedded in social constructivism [38]. The ZPD is defined as the distance between the actual developmental level, as determined by independent problem-solving, and the level of potential development, as determined through problem-solving under adult guidance or in collaboration with more capable peers [37]. The ZPTD is the distance between what the teacher can do with scaffolding and without the help of the facilitator [36]. The ZPTD stages are as follows: In Stage 1, teachers, as students, are required to reflect on their prior experiences and assumptions. In Stage 2, or the expert-other phase, teachers (i.e. expert others, usually known as knowledgeable others) are assisted to be more self-directed individuals. In Stage 3, the internalisation phase, teachers, through critical reflection and journaling, start developing their footing and voice and slowly develop a more nuanced teaching philosophy. Lastly, in Stage 4, the recursion or de-automatisation phase, also seen as the theory-to-practice stage, teachers confront the dichotomy of theory and practice in all their intensity.

Against this background and theoretical framework, this study developed a framework on the simulation-embedded scaffolding of PBL for science teachers' self-directedness, which stood as a hypothesis. Further development of empirical data and tools is needed through teacher professional development. The proposed framework for teachers' problem-based learning and teaching self-directedness in teaching (PBLT-SD) is presented in Figure 1.

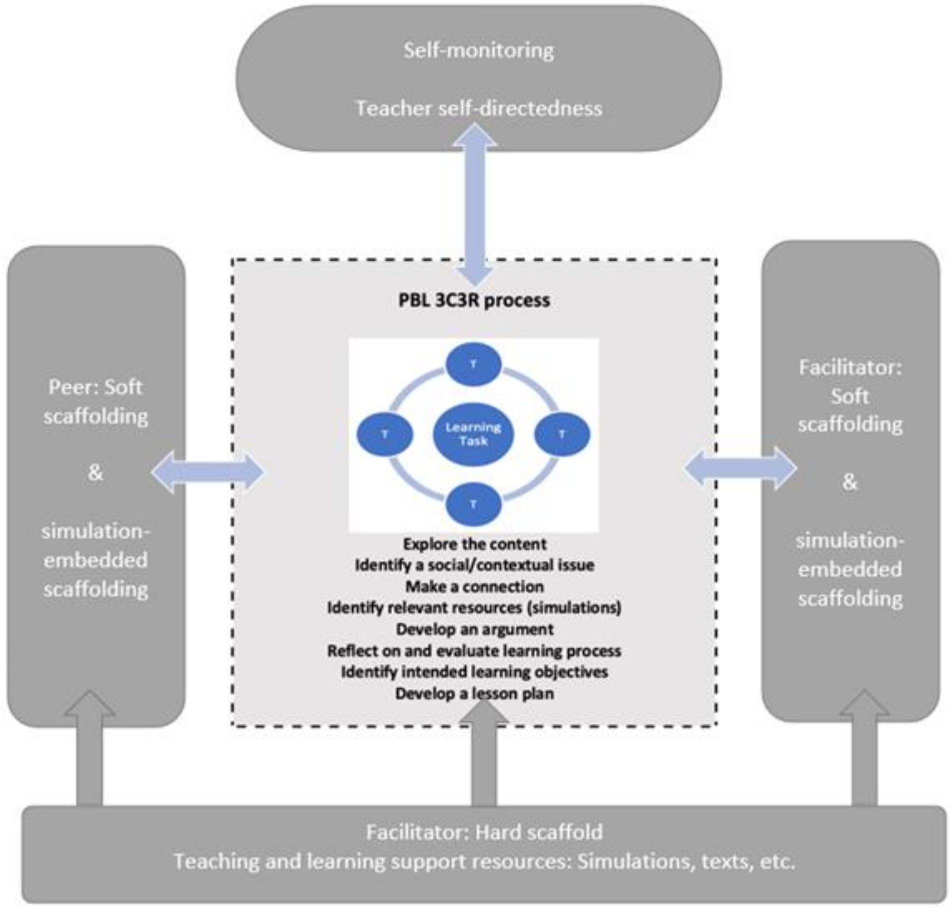

Fig. 1. Framework for teachers' PBLT-SD

This framework was developed based on a framework [27] for hard, peer and teacher scaffolding in technology-enhanced classroom environments. In the beginning, starting from the bottom (see Figure 1), a facilitator is expected to prepare hard scaffolding, using relevant teaching and learning resources such as simulations, science content knowledge and PBL principles. This is followed by a phase where the facilitator should promote soft scaffolding among peers, where there is positive interdependence on simulation-embedded scaffolding. Hard scaffolding can be seen as static support that can be anticipated; in other words, it is planned in advance, based on the typical difficulties experienced by the participants in executing a task. On the other hand, soft scaffolding is dynamic and based on the circumstances at the time. For example, the knowledgeable other is required to establish the participants' understanding continuously and provide timely support based on their responses. Science teachers are expected to work with PBL problems using the process of the Second Generation of the 3C3R PBL Problem Design Model. The model is used to explore science content knowledge, identify a contextual issue, connect the identified issue with the classroom content, identify relevant resources, develop an argument of engagement, reflect on and evaluate the anticipated learning processes, identify potential learning objectives and develop a lesson plan. Science teachers should monitor themselves for their self-directedness in learning and teaching with innovative teaching and learning strategies. While teachers' self-directedness for teaching is enhanced, they may need to tap into the PBL 3C3R process while planning and designing a PBL problem for a new science topic.

The hard, peer and teacher scaffolding framework is based on the implementation of inquiry-based learning, rather than PBL [27]. Furthermore, the framework is based on students' perceptions, rather than those of the teachers. On the other hand, the framework developed in this study is related to a pedagogical framework for teaching and learning with inquiry tools [33]. The framework is also designed to enhance teachers' pedagogical content knowledge. However, this framework may be difficult to implement, as its components do not clearly show how the model begins. The framework presented in this study may be appropriate for enhancing teachers' self-directedness for teaching.

This paper argues that the PBLT-SD framework developed in this study may be easier to apply, also by teachers, as these participants are expected to monitor their self-directedness for teaching. Any more knowledgeable other (as put by Vygotsky) may guide others applying this framework. In bringing it all together, this paper argues that PBL may be better referred to as the problem-based learning and teaching (PBLT) strategy, as PBL is not independent of the teacher. In fact, PBL depends heavily on the teacher's self-directedness, acting as a guide and facilitator during the learning process. It is necessary to understand the specific characteristics of this framework and how they are interrelated, which may help develop collaboration among them during the implementation of PBL. The authors of this paper recognise that there are many more variables in designing this process that are important in pedagogical and contextual practices. However, it should be borne in mind that this framework was observed in the South African context in the teaching and learning of science subjects. The following research question guided this study: How can science teachers' self-directedness in implementing PBL be enhanced in a teacher professional development intervention?

2. Methodology

This intervention-based study followed a descriptive quantitative research design. The study was conducted in North West, one of the nine provinces of South Africa. This province is divided into four education districts. A cluster sampling technique was employed, and the four districts were taken as clusters. Systematic random sampling was then used to sample 10 science teachers from each cluster. A total of 40 science teacher participants were sampled. It is important to mention that this study emerged from a larger mixed-method research project. However, this paper reports on the quantitative research aspect. A simulations questionnaire [39] was adapted, a PBL questionnaire [40] was adapted and a reflective portfolio was developed by the authors. These three instruments were used as data generation instruments to generate quantitative data. The quantitative data were analysed using descriptive and parametric statistics. The Statistical Package for the Social Sciences software was used for the data analysis, and the Shapiro–Wilk and Wilcoxon signed-rank tests were employed. The Interstate New Teacher Assessment and Support Consortium performance standards scoring rubric [41] was adapted to analyse the participants' implementation of PBL in the portfolio.

2.1 Methods: Teacher Professional Development

A three-day teacher professional development workshop was conducted for the science teacher participants (n = 40) mentioned above. The participants worked collaboratively and cooperatively in groups of six members, guided by the theoretical framework chosen for the study. The participants were advised to remain in their groups for the entire professional development intervention. The topic of the three states of matter was used as content knowledge, as it is universal across school science subjects and all grades. In the first workshop (Day 1), the authors worked with the participants to formulate objectives for professional development, that is, beginning with Stage 1 of the ZPTD. Determining the objectives of teacher professional development relates to the bottom section (facilitator: hard scaffold) of the proposed framework (see Figure 1). The participants were introduced to the concept of self-directedness in teaching. Then PBL as a teaching and learning strategy and how it can be implemented in the classroom were set out. After that, the Second Generation of the 3C3R PBL Problem Design Model was used by the participants to plan and design PBL problems. This model was twofold in that it was used to both generate and assess PBL problems. To assess the PBL problems planned and designed by the participants for implementation, the authors developed the 3C3R PBL Problem-Related Quality Rating Form. This rating form was used to measure the extent to which the components of the Second Generation of the 3C3R PBL Problem Design Model were adhered to or shown, using a positive and negative affect scale developed by Simmons and Lehmann [42].

On the second day of the workshop, the participants were introduced to simulations showing the relevance and benefits thereof in the teaching and learning of science. The participants' exposure to the concept of self-directedness in teaching, the processes of PBL and the use of simulations took place following Stage 2 of the ZPTD, as, in this scenario, the authors were the most knowledgeable others. As the participants had been exposed to both PBL and simulations, they were required to integrate the two by planning and designing PBL problems relating to the three states of matter within their groups. This was Stage 3 of the ZPTD, where the participants internalised and applied their newly acquired knowledge. It is important to mention that Stages 2 and 3 of the ZPTD relate to the PBL 3C3R process section, interlinking with soft scaffolding by the facilitator (most knowledgeable other) and peers on the sides of the proposed framework (see Figure 1).

In the third workshop, the participants presented the PBL problems they had formulated in the form of a lesson plan to everyone in the workshop. Anyone could comment on it, make suggestions or ask questions. The problems were then evaluated and refined to align with the implementation of PBL and science content knowledge and the application of simulations so that teachers can implement them in their classrooms while teaching the three states of matter. Presenting the formulated PBL problems and intended simulations was the beginning of Stage 4 of the ZPTD, namely de-automatisation. This stage related to teachers' self-monitoring, which enhances their self-directedness in teaching. Lastly, each participant was provided with a portfolio with processes to carry out and document their implementation of PBL. This action finalised Stage 4 of the ZPTD by putting theory into practice. The participants were visited at their schools to observe their implementation of PBL.

3. Results and Discussion

The Shapiro–Wilk test was used to determine the analysis carried out for the PBL instrument. The results of the study showed a significant difference in the participants' perceptions of PBL after attending the intervention and implementing PBL partnered with simulations. This result is interesting, given that the instrument in question was adapted and used in this context for the first time. Furthermore, the results of the study are in line with those of another study [35], which showed the successful implementation of PBL partnered with simulations. Therefore, the conclusion was made that there was a significant difference between the teacher participants' perceptions of simulations before and after the intervention. To compare the pre- and post-intervention results, the Wilcoxon signed-rank test was conducted. The results of this study showed that the intervention positively influenced the participants' perceptions of their self-directedness in teaching, as the mean was higher after attending the intervention. These results corroborate the results of another study [34], as the participants could go through all four stages of the ZPTD. The Wilcoxon signed-rank test calculated was found to be statistically significant. Therefore, the null hypothesis, which states that the median of differences between the pre- and post-TPD data equals zero, was rejected. It was concluded that there was a significant difference between the teacher participants' perceptions of simulations before and after their introduction to simulations during the intervention.

Interrater reliability coefficients were calculated for each of the teacher assessment and support consortium principles in the teacher participants' portfolios and their overall level of proficiency in the implementation of PBL, respectively. For this, the statistical software Stata was used. Regarding the principle of 'adaptation of process and role players of PBL method to meet diverse learners' learning needs and styles', it was found that fewer participants ($n = 3$) scored 4, showing clear, convincing and consistent evidence. Most of the participants ($n = 5$) scored 2, showing limited evidence of understanding the process of PBL during classroom implementation and the assumption of roles. The results of this study about the challenges of implementing PBL for the first time are similar to those of other studies [30, 31]. Regarding the principle of 'evidence of use of simulations', the results showed that most of the teacher participants ($n = 7$) were able to use simulations, scoring 4. These results are in line with those of another study [34], which showed that teachers strongly preferred being self-directed in domains specific to subject matter, digital devices and multimedia. Likewise, in the current study, the participants showed clear, convincing and consistent evidence of successfully using simulations in their classrooms. Regarding the principle of 'assessment of learners' learning to improve teaching', the results showed that only one of the participants obtained a score of 1, which denotes no evidence of any assessment. This particular participant did not assess the learners' work or guide the learners to assess themselves. Furthermore, the results showed that half of the participants scored 2 (limited evidence). 'Limited evidence' refers to a teacher participant's portfolio containing only one form of assessment. Clear evidence (score of 3) was provided by two participants, reflecting that their portfolios contained both teacher- and learner-based assessments. Lastly, one participant obtained the highest score of 4, showing clear, convincing and consistent evidence of both teacher- and learner-based assessments.

These results highlighted that science teachers may require more support in assessing learners in PBL activities. Therefore, lengthy teacher professional development for self-directedness in teaching may be advisable. It may also be necessary to spend more time on Stage 2 ('most knowledgeable other' stage) of the ZPTD. The proposed framework of this study shows how science teachers' self-directedness can be enhanced in teaching and learning through an intervention. In addition, the PBLT-SD framework developed here may be easier to follow by other teachers, as they are expected to monitor their self-directedness in teaching. Any more knowledgeable other, as put by Vygotsky [37], can guide others when this framework is applied.

4. Conclusion

The results of this study illustrated a significant difference in the science teacher participants' perceptions of using interactive simulations, PBL and their self-directedness after participating in an intervention. The intervention combined a teacher professional development intervention and the classroom implementation of PBL, partnered with simulations. Therefore, it corresponded well with the theoretical framework of the study, namely ZPTD. Recognising that a teacher should be a lifelong learner, this study recommends more professional development initiatives for teachers based on personal, national and professional needs. Applying the framework proposed in this study, such professional development initiatives can help teachers cope with today's ever-changing and globally interconnected world. By doing so, teachers' self-directedness in implementing innovative teaching and learning strategies may be enhanced.

REFERENCES

[1] Kolmos, A., Holgaard, J.E. & Routhe, H.W. "Understanding and designing variation in interdisciplinary problem-based projects in engineering education", Education Sciences, 2025, 15(2), Article 138, https://doi.org/10.3390/educsci15020138.
[2] Roliak, A., Dutka, H., Mylytsya, K., Matiienko, O. & Oliinyk, N. "Problem-based learning in pedagogic tertiary education: European context through Denmark environment. Independent", Journal of Management & Production, 2021, 12(3), s071-s084.
[3] Cronje, A. "Epistemological border crossing between western science and indigenous knowledge and its implications for teacher professional development", [Doctoral dissertation, University of Johannesburg], 2015.
[4] Golightly, A. & Muniz, O.A. "Are South African geography education students ready for problem-based learning?", Journal of Geography in Higher Education, 2013, 37(3), 432-455.
[5] Sebatana M.J. "Contextualised teaching of a physical science topic using problem-based learning: A case study", Proceedings of the 32nd Annual Meeting of the Southern African Association of Research in Mathematics and Science Technology Education (SAARMSTE) Conference, hosted by International University of Management in Collaboration, Republic of Namibia (16-18 January 2024), 320-242.
[6] Lambros, A. "Problem-based learning in middle and high school classrooms: A teacher's guide to implementation", Thousand Oaks, Corwin Press, 2004, 1-117.
[7] Shin, S., Brush, T.A. & Glazewski, K.D. "Examining the hard, peer, and teacher scaffolding framework in inquiry-based technology-enhanced learning environments: Impact on academic achievement and group performance", Educational Technology Research and Development, 2020, 68(5), 2423-2447.
[8] Department of Basic Education (South Africa). "Guidelines for inclusive teaching and learning", Pretoria, Government Printing Works, 2010, www.thutong.org.za/Learningspaces/InclusiveEducation.aspx.
[9] Akçay, B. "Problem-based learning in science education", Journal of Turkish Science Education, 2009, 6(1), 26-36.
[10] Wu, Y., Song, D., Dong, Y., Zhong, Q., Gao, S., Sun, J., Fang, S., Zhi, S., Wang, R. & Sun, J. "Effects of a grouping intervention using the Felder-Silverman learning style model on problem-based learning among nursing students: A randomized controlled trial", Nurse Education Today, 2025, 1, 145, 106489
[11] Barrows, H.S. & Tamblyn, R. "Problem-based learning: An approach to medical education", New York, Springer, 1980.
[12] Borhan, M. "Problem-based learning (PBL) in teacher education: A review of the effect of PBL on pre-service teachers' knowledge and skills", European Journal of Educational Sciences, 2014, 1 (1), 76-87, https://doi.org/10.19044/ejes.v1no1a9.

[13] De Simone, C. "Problem-based learning in teacher education: Trajectories of change", International Journal of Humanities and Social Science, 2014, 4(12), 17-29.
[14] Golightly, A. "The influence of an integrated PBL format on geography students' perceptions of their self-directedness in learning", Journal of Geography in Higher Education, 2018, 42(3), 460-478.
[15] Ansarian, L. & Teoh, M.L. "Problem-based language learning and teaching: An innovative approach to learn a new language", Singapore, Springer, 2018, https://doi.org/10.1007/978-981-13-0941-0_2.
[16] De Beer, J. "The elephant in the room: The work-integrated learning of student teachers, and the influence of teacher educator scholarship on their professional development", Proceedings of the ISTE Conference on Mathematics, Science and Technology Education, Kruger National Park, October 2017, https://doi.org/10.4102/satnt.v33i1.1179.
[17] Goodnough, K.C. & Hung, W. "Engaging teachers' pedagogical content knowledge: Adopting a nine-step problem-based learning model", Interdisciplinary Journal of Problem-based Learning, 2008, 2(2), 61-90.
[18] Hung, W. "The 3C3R model: A conceptual framework for designing problems in PBL", Interdisciplinary Journal of Problem-based Learning, 2006, 1(1), 55-77.
[19] Hung, W. "Problem design in PBL", in M. Moallem, W. Hung & N. Dabbagh (eds.), The Wiley handbook of problem-based learning, 2019, pp. 249-274, New Jersey, John Wiley & Sons.
[20] Raemdonck, I, Thijssen, J.G.L. & De Greef, M. "Self-directedness in work-related learning processes: Theoretical perspectives and development of a measurement instrument", in M. Göller & S. Pallonimie (eds.), Agency at work: An agentic perspective on professional learning and development, London, Springer, 2017, pp. 401-423.
[21] Verster, M., Mentz, E. & Du Toit-Brits, C. "Requirements of the 21st century for teachers' curriculum as praxis: A theoretical perspective", Literacy Information and Computer Education Journal, 2018, 9(3), 461-463.
[22] Guglielmino, L.M. "The case for promoting self-directed learning in formal educational institutions", SA-eDUC Journal, 2013, 10(2), 1-18.
[23] Ahmad, B.E., Ozturk, M., Abdullah, M.A. & Majid, F.A. "A comparative study on the relationship between self-directed learning and academic achievement among Malaysian and Turkish undergraduates", Gading Journal for Social Sciences, 2019, 22(1), 1-9.
[24] Zenios, M. "Educational theory in technology enhanced learning revisited: A model for simulation-based learning in higher education", Studies in Technology Enhanced Learning, 2020, 1(1), http://clok.uclan.ac.uk/35879/.
[25] Akgun, S. & Greenhow, C. "Artificial intelligence in education: Addressing ethical challenges in K-12 settings", AI and Ethics, 2021, 1-10.
[26] Haataja, E., Moreno-Esteva, E.G., Salonen, V., Laine, A., Toivanen, M. & Hannula, M.S. "Teacher's visual attention when scaffolding collaborative mathematical problem solving", Teaching and Teacher Education, 2019, 86, 1-15.
[27] Shin, S., Brush, T.A. & Glazewski, K.D. "Examining the hard, peer, and teacher scaffolding framework in inquiry-based technology-enhanced learning environments: Impact on academic achievement and group performance", Educational Technology Research and Development, 2020, 68(5), 2423-2447.
[28] McCrary, N.E. & Mazur, J.M. "Conceptualizing a narrative simulation to promote dialogic reflection: Using a multiple outcome design to engage teacher mentors", Educational Technology Research and Development, 2010, 58(3), 325-342.
[29] Dhurumraj, T., Ramaila, S., Raban, F. & Ashruf, A. "Broadening educational pathways to STEM education through online teaching and learning during COVID-19: Teachers' perspectives", Journal of Baltic Science Education, 2020, 19(n6A), 1055-1067.
[30] Goodnough, K. & Cashion, M. "Exploring problem-based learning in the context of high school science: Design and implementation issues", School Science and Mathematics, 2006, 106(7), 280-295.
[31] Navy, S.L. & Kaya, F. "PBL as a pedagogical approach for integrated STEM: Evidence from prospective teachers", School Science and Mathematics, 2020, 120(5), 285-296.
[32] Sebotsa, T., De Beer, J. & Kriek, J. "Self-directed learning and teacher professional development: An adapted profile of implementation", 2019, https://doi.org/10.20472/TEC.2019.008.025.
[33] Kim, M.C., Hannafin, M.J. & Bryan, L.A. "Technology-enhanced inquiry tools in science education: An emerging pedagogical framework for classroom practice", Science Education, 2007, 91(6), 1010-1030.

[34] Louws, M.L., Meirink, J.A., Van Veen, K. & Van Driel, J.H. “Teachers’ self-directed learning and teaching experience: What, how, and why teachers want to learn”, 2017, Teaching and Teacher Education, 66, 171-183.
[35] Putranta, H. & Wilujeng, I. “Physics learning by PhET simulation-assisted using problem based learning (PBL) model to improve students’ critical thinking skills in work and energy chapters in MAN 3 Sleman”, Asia-Pacific Forum on Science Learning & Teaching, 2019, 20(1), 1-45.
[36] Warford, M.K. “The zone of proximal teacher development”, Teaching and Teacher Education, 2011, 27(2), 252-258.
[37] Vygotsky, L. “Interaction between learning and development”, in M. Gauvain & M. Cole (eds.), Readings on the development of children, Cambridge, Harvard University Press, 1978, pp. 79-91.
[38] Taber, K.S. “Mediated learning leading development – the social development theory of Lev Vygotsky”, in B. Akpan & T. Kennedy (eds.), Science education in theory and practice: An introductory guide to learning theory, New York, Springer, 2020, pp. 1-18.
[39] Kriek, J. & Stols, G. “Teachers’ beliefs and their intention to use interactive simulations in their classrooms”, South African Journal of Education, 2010, 30(3), 439-456.
[40] Lao, H.C. “Development of a survey to examine the factors that motivate secondary education teachers’ use of problem-based learning (PBL)”, [Doctoral dissertation, North Carolina State University], 2016.
[41] Smith, P.L., Harris C.M., Sammons, L., Waters, J., Jordan, D., Martin, D., Smith, N. & Cobb, P. “Using multimedia portfolios to assess preservice teacher and P-12 student learning”, Action in Teacher Education, 2001, 22(4), 28-39.
[42] Simmons, C. & Lehmann, P. Tools for strengths' based assessment and evaluation, Springer, New York, 2012.