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Pedagogical Support Structures for Effective Implementation of Simulation-Based Innovation in Science Classrooms: Prospective Teachers' Perspectives

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Abstract

Effective utilisation of technology in the classroom relies on, among other factors, the roles, and actions of teachers, considering both opportunities and limitations presented by technology in representing the subject matter. Therefore, it is essential to examine the pedagogical practises employed by teachers when using technology to teach science. By use of an explanatory case study design with qualitative data sources such as focus group interviews, lesson artefacts and observations, this research adapted the Technological Pedagogical and Content Knowledge (TPACK) framework as a lens within a professional development framework to examine the pedagogical context of four prospective teachers as they designed and implemented simulation-based physics lessons in pairs. The objective was to gain in-depth understanding of the pedagogical support structures necessary for successful implementation of Physics Education Technology (PhET) simulation-based physics lessons, with a focus on promoting a learner-centred instructional approach in Ghanaian science classrooms. The findings suggest that the provision of minimal guidance through activity sheets, as well as facilitative strategies such as engaging prior knowledge, supervising learner activities, fostering discussion platforms and providing summaries, are crucial pedagogical support structures that drive learner-focused instructional processes when using simulations. The study advocate that central to the success attained with simulation-based lessons was the prospective teachers' developed TPACK as well as the content-sensitive and interactive affordances offered by PhET simulations, despite acknowledging their inherent limitations as technological tools.

Keywords prospective teachers, technology in teaching physics, simulation-based physics lessons, pedagogical support structures

Introduction

Pedagogical practises play a critical role in science education, influencing students' learning experiences and outcomes. Research studies (Banilower et al., 2013; Hmelo-Silver, 2004; Lou et al., 2011; Smetana & Bell, 2012) have explored various pedagogical practises employed by teachers in science education. For instance, Hmelo-Silver (2004) investigated the use of inquiry-based approaches in science classrooms. The study found that inquiry-based pedagogical practises, where students actively engage in investigating scientific phenomena promote deeper understanding, critical thinking, and scientific inquiry skills. Lou et al., (2011) examined the impact of collaborative learning on students' conceptual understanding in science. Findings revealed that collaborative pedagogical practises, such as group discussions, peer interactions, and cooperative problem solving, enhances students' engagement, knowledge construction, and conceptual understanding.

Furthermore, a study by Smetana and Bell (2012) explored the use computer simulations in science classrooms. The

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findings indicated that simulations support inquiry-based learning, conceptual development, and scientific reasoning when integrated effectively into pedagogical practises. Research has also examined the role of teacher professional development in promoting effective pedagogical practises in science education. Professional development arrangements that focus on enhancing teachers' content, pedagogical strategies and technological skills have been found to positively impact classroom instruction and student outcomes (Banilower et al., 2013). Literature in this respect seems to suggest that effective technology integration is not just about digital tools and their techno-centric capabilities, but also, about how: a) pedagogy and instructional practises align with technology integration, and b) teachers' roles, as adapted in instruction inform technology-based innovations to be effective in science classrooms. In relation to the former, several studies have examined the relationship between pedagogical practises and technology integration in science classrooms. For instance, Hsu, Chen and Chen (2016) found that teachers who embraced constructivist pedagogy, including collaborative learning, problem solving and inquiry-based instruction, were more successful in integrating technology into their teaching practises. These pedagogical approaches, apparently, provided students with opportunities to interact with technological tools, collaborate with their peers and construct their own knowledge.

Similarly, Sang, Valcke, van Braak and Tondeur (2017) explored the connection between student-centred pedagogy and technology integration in science classrooms. Their research revealed that student-centred approaches like project-based learning and flipped classrooms models facilitated effective integration of technology tools. These pedagogical practises encouraged students to take ownership of their learning, engage in hands-on activities and utilise technology resources for research, data analysis, and presentation of findings. On the latter, literature emphasises that teachers' roles and actions significantly influence the effective use of technology-based innovation in science classrooms. Apparently, teachers who adopt active roles, have positive beliefs, and attitude towards technology, and employ specific strategies such as scaffolding, modeling, and professional development opportunities are more likely to enhance student engagement, understanding and learning outcomes through technology integration (Davis & Shade, 2014; Ertmer, 2005; Hennessy, Deaney & Ruthven, 2016; Hew & Brush, 2007). Arguments presented herein suggest that teachers are not left out of the picture of effective technology integration prospects, in that they are empowered in their adoption of technology to create learner-centred environments that foster diverse learning styles and abilities owing to the affordances that technology offers in representing the subject matter.

The integration of instructional technology such as computer simulations into science classrooms has emerged as an important approach to meet evolving needs of 21st century education. Numerous research studies have explored the potentials of computer simulations for enhancing and improving science teaching across different educational levels (Agyei & Agyei, 2021a; Antonio, & Castro, 2023; da Silva & de Vasconcelos, 2022; Ogegbo & Ramnarain, 2022). Simulations offer interactive experiences, promote learner-centred instruction, and contribute to the development of content knowledge and science process skills (Agyei, Jita & Jita, 2019; Almasri, 2022; Syafriyanti, 2023). Furthermore, literature highlights the influence of simulations on teachers' adoption of constructivist-oriented pedagogical structures that prioritise learners' needs and subject content (Chang, 2013; Haryadi & Pujiastuti, 2020; Smetana & Bell, 2012; Vlachopoulos & Makri, 2017). This seems to suggest that effective integration of computer simulations in science classrooms necessitates an understanding of pedagogical practises and contexts that support students' learning. The teacher's responsibility in utilising simulations in this respect, therefore, extend beyond transmitting knowledge to facilitating and creating a conducive learning environment (Cox et al., 2004; Ertmer & Ottenbreit-Leftwich, 2010; Majumdar, 1997; Scheurs & Dumbraveanu, 2014). This paradigm shift towards learner-centred approaches requires teachers to be skilled and creative in their application of simulations (Cox et al., 2004). Guidelines proposed by Bell and Smetana (2008) suggest integrating simulations as supplementary instructional strategies, fostering student-centred instruction with simulations, recognising the limitations of simulations and prioritising content over simulations' technocentric capabilities, as essential to successful implementation process with simulations. Despite the positive impact of simulations on teaching and learning, limited research has specifically focused on the teacher's role in utilising such technology in Ghanaian science classrooms. Consequently, further research is needed to explore the factors that inform teachers' use of simulations and the specific pedagogical contexts that must be considered to effectively integrate computer simulations into science classrooms in the context of Ghana.

Computer simulations such as Physics Education Technology (PhET) simulations (also referred to as PhETs) have been described widely as "high-tech tools for teaching physics" owing to its characteristic features that support learner-centred instructional processes (Finkelstein et al., 2006, p.1) and potential for promoting interactivity in science classrooms (Agyei & Agyei, 2021b; Price, Wieman & Perkins, 2019). Finkelstein and co-researchers identified six features that project PhET simulations as high-tech tools in physics classrooms. Firstly, these PhETs possess the capacity to foster engaging and interactive interfaces that allow room for users to explore, interact and manipulate parameters to achieve their learning goals—thereby promoting student engagement (Redish, 2003). Secondly, they facilitate dynamic feedback to students as they engage with the simulation environment. This is vital for developing conceptual understanding and establishing relationships among explored concepts (Clark & Mayer, 2003). Thirdly, PhETs follow prior knowledge, necessitating some level of guidance or support for effective learning outcomes. Fourthly, they provide a workspace for play and tinkering, allowing "systematic play", "open-ended investigations", and hands-on learning experiences (Finkelstein et al., 2006, p. 2). Fifthly, these simulations offer visual access to conceptual physical models, enabling students to visualise microscopic and abstract physics systems that are challenging to observe directly. Lastly, PhET simulations incorporate productive constraints (Perkins et al., 2004) to keep students focused on specific tasks and support their gradual understanding of key concepts.

The question of what level of guidance is needed for effective teaching with PhET simulations arises in relation to the sixth characteristic feature. Adams, Paulson, and Wieman (2008) explored different levels of guidance and their impact on engaged exploration with interactive simulations. Their study identified four levels of guidance that could be employed with PhET simulations: no instructions/guidance (Type A), driving questions (Type B), gently guided (Type C), and strongly guided (Type D). Through student interviews, the researchers found that the levels of guidance facilitating engaged exploration were either no guidance or guidance in the form of driving questions. Apparently, Types A and

B encouraged students to play with the simulations, talk about their actions aloud, and explore the simulations using their own questioning, resulting in deeper understanding and the development of mental frameworks. Findings in this regard suggested that PhET simulations, when used with minimal guidance or no guidance, foster students' innovation and enable them to become constructive learners.

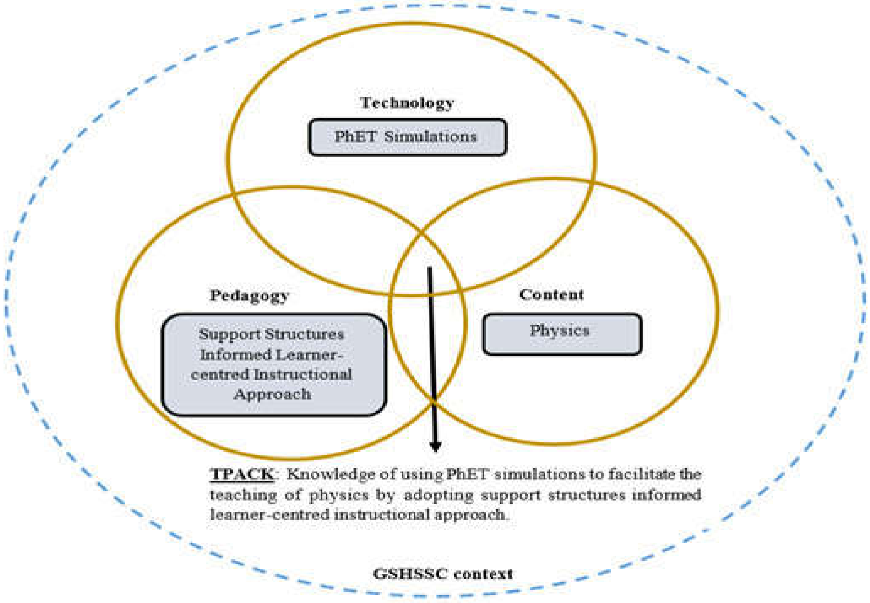
Among the different levels of guidance, Type B, which involves driving questions, appeared to be the most effective for meaningful learning and interactivity with PhET simulations. The authors argued that "minimal but nonzero guidance with PhET simulations promotes optimum engaged exploration and learning" (Adams et al., 2008, p.1) indicating that Type B guidance can be considered as minimal guidance. This finding informed PhETs' use in the current study, as of interest in this study was to ascertain whether this argument holds same for prospective teachers in the context of this research with regards to the pedagogical structures, they adopted for teaching with the PhETs. Finkelstein et al.'s ideas as discussed, highlights the various pedagogical structures that teachers can adopt when using PhETs for physics instruction and, emphasises how teachers can leverage on the affordances of PhETs to facilitate learner-centred instruction through pedagogical support structures that are grounded in theory.

However, gaining valuable insights into teachers' pedagogical practises with technology such as simulations is not devoid of theory, but theory informed. Various theoretical frameworks and models have been proposed to explore the relation between pedagogy and technology integration. One such framework is the Technological Pedagogical and Content Knowledge (TPACK) framework (Mishra & Koehler, 2006) which consists of seven different knowledge domains: 1) Technology knowledge (TK), 2) pedagogical knowledge, 3) Content knowledge, 4) Technological pedagogical knowledge (TPK), 5) Technological content knowledge (TCK), 6) Pedagogical content knowledge (PCK) and 7) Technological, Pedagogical and content knowledge (TPACK) (Koehler, Mishra & Cain, 2013). TK, PK and CK represent the three major components of teachers' knowledge. TPK, TCK, PCK and TPACK represent the various interactions that exist between and among the major components of the TPACK model (Koehler et al., 2013).

According to Chai, Koh, and Tsai (2010, p 63), TK, PK and CK are "knowledge about how to use ICT hardware and software and associated peripherals", "knowledge about students learning, instructional strategies, different educational theories and assessment methods", and "knowledge of subject matter" respectively. TPK is the knowledge a teacher has about the potential as well as constraints of technology in providing a platform for different teaching strategies (Koehler & Mishra, 2008). TCK refers to knowledge about the different ways in which "… technology and content are reciprocally related" (Mishra & Koehler, 2006, p 1028). PCK is referred to as the knowledge a teacher requires to develop and enact an effective instruction that is content-driven (Shinas, Yilmaz-Ozden, Mouza, Karchmer-Klein & Glutting, 2013). The last domain, TPACK refers to the unique body of knowledge that is highly dependent on a teacher's understanding of how the interplay between TK, PK and CK can be realised and applied for the development of an effective technology-integrated lessons (Agyei & Voogt, 2012; Harris et al., 2009). It is important to state that in the context of this study, the last domain, TPACK was of much interest.

Several research studies have examined the application of TPACK in the context of simulation-based innovation. For instance, Koh et al., (2013) investigated the TPACK development of science teachers using simulations in their instructional practises. The study found that teachers with higher TPACK scores were more proficient in selecting and integrating appropriate simulations, designing effective learning activities, and promoting student engagement and inquiry. Eick et al. (2017), explored TPACK development of pre-service teachers in using simulations. Findings revealed that TPACK helped pre-service teachers to overcome technological challenges, such as limited access to technology resources and technical difficulties, by focusing on pedagogical strategies and content knowledge integration. Seemingly, these findings situate the TPACK framework as a valuable lens for understanding the integration of simulation-based innovations science classroom for the context of Ghana and hence, establishes TPACK as the specific knowledge pre-service teachers need to successfully design and implement simulation-based innovations for the realisation of a learner-centred instructional approach. On these grounds, the present research adapted Agyei & Agyei (2021b)'s operationalised model of TPACK as a lens within a professional development framework to examine the pedagogical context of four prospective teachers as they designed and implemented simulation-based physics lessons with the aim to identify and gain in-depth understanding of the pedagogical support structures that inform the implementation of such technology-based innovation to be successful in promoting a learner-centred instructional process in science classrooms. The technology tool of interest was Physics Education Technology (PhET) simulations (PhETs) —specifically, Bending Light (BL) and Build an Atom (BA) PhETs were considered, and the content was physics. Support structures informed learner-centred instructional approach was the pedagogy adopted. These operationalisations were considered for the specific case of the Ghanaian Senior High School Science Classroom (GSHSSC) context as indicated in Figure. 1.

Figure 1 Operationalized TPACK as situated in the Ghanaian senior high school science classroom context



[Adapted from Agyei and Agyei (2021b)]

Based on the operationalisations considered, this research advocates the need for teachers to meet the 21st century educational standards which demand authentic, dynamic and transformative learning environments, wherein teachers' roles with technology in the science classroom, as driven and entrenched in their technology-oriented knowledge and skills extend beyond recognising the affordances of technology as instructional tools to providing pedagogical support structures that facilitates interactions between learners, technology, and teachers themselves in learning the subject matter. Consequently, the study addresses the question: "How do the pedagogical support structures adapted by teachers in their instructional process with simulations facilitate effective learner-centred instruction in the Ghanaian science classrooms?".

Table 1 **Summary of the PhETs-based physics lessons developed and implemented by participants**

Design Team (DT) designation	Participant pseudonyms	Designated name for lesson	Physics topic	Name of PhET used
DT1	PTP1 PTP2	SBPL_1	Reflection and refraction of light	Bending Light
DT2	PTP3 PTP4	SBPL_2	Structure of the atom	Build an Atom

Research Methods

An explanatory case study design was employed in this research, focusing on four prospective physics teachers participating in a professional development framework. The objective was to investigate the pedagogical practises that contribute to the effectiveness of simulation-based physics lessons in science classrooms, specifically within the context of Ghanaian classrooms. Participants of the study were final-year students enrolled in the science teacher education programme at a public university in Ghana. Purposive sampling was employed, selecting participants based on their availability and commitment. Participants were informed about the study and provided with an information sheet and consent form in advance allowing them sufficient time to decide whether to participate. To protect the anonymity of the participants, pseudonyms were used, as indicated in Table 1.

To facilitate the participants' development of technology-oriented competencies for integrating PhET simulations into their teaching practises, a two-phased professional development arrangement, referred to as 2P-PDA, was employed. The first phase involved an initial training workshop where the participants received coaching on the development and implementation of simulation-based interventions. This included discussions on the TPACK framework as a technology integration framework, its applications, and implications for teachers, as well as introductory lectures on PhET simulations and their affordances for physics instruction. Hands-on activities on PhET use for representing physics concepts and demonstrative activities with exemplary curriculum materials were also conducted by the researchers. In the second phase, participants were engaged and tasked with designing, developing, and implementing their own TPACK driven simulation-based lesson artefacts based on their personal experiences with the exemplary curriculum materials designed by the researchers. Specifically, participants worked in two-member design teams and utilised the Bending Light and Build an Atom PhET simulation environments. They tested their innovations in two rounds of microteaching sessions where they taught with their simulation-based lesson designs in teams among themselves. A summary of the two PhET simulation-based physics lessons (SBPLs) designed and implemented by participants in the study is provided in Table 1. Both lessons, as indicated in Table 1, were designed to be exploratory in nature, reflecting a classroom situation in which both the teacher and learners have access to a computer with the selected PhET downloaded for offline use.

The choice of physics content assumed that the learners had been previously taught the selected physics content without the aid of technological tools, hence the lessons were designed for the purpose of reinforcement. Due to the potentials of the BL and BA simulation environments, the two design teams considered specific learning objectives for lessons on “Reflection and refraction of light” and “Structure of an atom” respectively. The interactive learning objectives depicted in Table 2 were included to explicitly show how the BL and BA simulation environments were incorporated to achieve the curriculum-informed learning objectives for each selected physics topic.

Qualitative data was collected through focus group interviews (FGIs), direct observation, and analysis of lesson artefacts designed by the participants. The use of multiple sources

Table 2 Curriculum-informed learning objectives the BL and BA simulation environments were intended to achieve

Environment	**BL simulation**	**BA simulation**
Specific objectives	At the end of the lesson, students should be able to: i. verify the laws of reflection and refraction. ii. determine the refractive index of glass and water using Snell’s law.	At the end of the lesson, students should be able to identify: i. element on the periodic table. ii. symbol of the element. iii. group and period of the element. iv. net charge of the element. v. mass number of the element.
Interactive learning objectives	At the end of the lesson, students should be able to use Physics Education Technology (PhET) simulation entitled: bending light guided by exploratory activities on reflection and refraction of light to: i. observe how reflection and refraction take place. ii. manipulate the various elements of the simulation to identify the angles of incidence, reflection, and refraction. iii. compare how the angle of reflection and refraction changes as the angle of incidence is varied.	At the end of the lesson, students should be able to use Physics Education Technology (PhET) simulation entitled: Build an Atom guided by exploratory activities on the structure of an atom to: i. identify the various element on the periodic table by varying the number of protons. ii. verify the effect of protons and electrons on the net charge readings. iii. identify the group and period of metals, metalloids, non-metals and rare/ inert gases.

aimed to ensure triangulation and enhance the validity of the findings. Focus group interviews were conducted after each of the two microteaching sessions in which the prospective teachers taught among themselves. Two focus group discussions were organised for the PTPs to reflect on the pedagogical context they considered in the design and implementation of their respective PhET-based lessons. The primary aim was to identify the specific support structures that contributed to the effectiveness of the lessons in promoting a learner-centred mode of instruction. Sample questions posed during the FGIs included: 1) what instructional approach did you, as teachers, adopt in delivering your simulation-based lessons? 2) What role did the teacher(s) play during the implementation of the PhET-based lessons? and 3) What support structures do you believe contributed to the effectiveness of the simulation-based lessons? In addition to the FGIs, the lesson artefacts created by the PTPs for both SBPLs served as qualitative data sources in this study. These artefacts included PhET simulation-based lesson plans, activity sheets and presentation slides. Direct observation was employed as a data collection method, during which the researchers maintained a logbook to record detailed and comprehensive accounts of the activities and events that took place during the instructional process with the SBPLs. Areas of interest that were observed included the teaching approaches adopted and the support structures implemented by the PTPs during the implementation of the SBPLs in the microteaching sessions.

The data collected through FGIs, analysis of lesson artefacts and direct observation were subjected to qualitative data analysis. For the FGIs, the recorded responses to the sample questions were transcribed verbatim. Thematic analysis was then applied to identify recurring patterns, themes and categories related to instructional approaches, teacher roles, and support structures mentioned by the prospective teachers. The identified themes were further analysed to explore their connections and significance in facilitating effective simulation-based lessons. The lesson artefacts were carefully reviewed and then content analysis was employed to identify the presence of specific support structures embedded within the materials. This analysis involved identifying the strategies, resources, and guidance provided in the lesson artefacts that aimed to enhance student engagement, interaction and understanding of the physics concepts explored. The logbook entries from the direct observations were analysed through descriptive analysis. The researchers' detailed accounts of the teaching approaches and support structures implemented by the PTPs were examined to identify common practises and notable instances of effective pedagogical support.

To ensure rigor and credibility of the findings, a process of triangulation was employed by comparing the data from different sources. The themes and patterns identified in the FGIs were cross-referenced with the information obtained from the examination of the lesson artefacts and direct observation. The findings from the data analysis were then interpreted and synthesised to address the research objectives, providing insights into the prospective teachers' pedagogical support structures for the effective implementation of simulation-based innovation in physics instruction.

Findings

As the research was purposed to gain understanding into the pedagogical practises that informed the SBPLs to be effective in promoting learner-centred mode of instruction, it was deemed necessary to first find out the participants' perceptions about the mode of instruction that they used in the delivery of their respective lessons. Evidence from the qualitative data sources employed in the study, showed that for all the two SBPLs implemented, the PTPs believed that their mode of instruction was learner-centred. This was revealed during the focus group discussion sessions after each lesson, where participants were asked to share their impressions about the teaching method they adopted during the implementation processes of the two lessons. Two of the PTPs who witnessed the enactment of the SBPL_1 as learners had the following to say on this issue:

> PTP3 *The lesson was student-centred, eventually, we did 80% of everything. The teacher only came in to give us a summary of the activities we had done in our group during the lesson. So, he was a guide…*
>
> PTP4 *The lesson was student-centred, the teacher had to do a little and then, come to summarize the solution for us. So, I think that one, he guided us.*

Similarly, with regards to SBPL_2, one the participants, who served as a learner in during the implementation process hinted the following:

> PTP1 *in my view, the approach was learner-centred since all the activities were engaging and … the teacher (referring to PTP4 who enacted the SBPL_2 lesson) provided some kind of guidance on the activity sheet for us to work on our own; he only came in to summarize everything that we had done after our group discussions…*

The PTPs who enacted the lessons for each DT has the following to say about their teaching approaches:

> PTP3 *I was the facilitator, a guide, and with the simulations, my approach was student--centred; students did most of the activities. Also, it was student-centred because, it as interactive, students were given instructions and they interacted with the simulation's environment, discussed among themselves that is the corporation, then they constructed their own knowledge, discussed, and came to a consensus...*
>
> PTP4 *... my instructional method was student-centred because, I engaged them (referring to her learners) almost 80% of the lesson period.*

Evidence as presented here seem to hint that the PTPs from DT1 and DT2 who taught the two lessons assumed the roles of facilitators; suggesting that the facilitating roles adopted by the prospective teachers in the implementation of the lessons were crucial for mediating learner-centred instructional process with the SBPLs.

The results also showed that the simulation-based lessons were effective in promoting learner-centred instruction because of the pedagogical support structures that were adopted by PTPs in the design and implementation of both SBPL_1 and SBPL_2. These were reflected in: 1) the facilitative strategies that were employed by the teachers during their lessons' delivery and 2) the minimal level of guidance provided on the activity sheets (that was developed by the Design Teams) to facilitate learners' exploration of the simulation environment during the instructional process.

Facilitative Strategies Adopted by Prospective Teacher Participants

Four facilitative strategies were identified in this research based on the evidence from the FGIs and the lesson artefacts designed by PTPs. These involved: 1) engaging prior knowledge (EPK); 2) supervising learner activities; 3) fostering discussion platforms; and 4) providing summaries. In the subsequent sections we elucidate how these facilitating modes were orchestrated in the instructional discourse with the simulation-based lessons to promote learner-centred mode of instruction for the context of the study.

Engagement of Prior Knowledge (EPK)

Engagement of learners' prior knowledge served as one of pedagogical means by which PTPs introduced their respective SBPLs and supported their learners to recall and reflect on physics concepts that were relevant for understanding the topics: "Reflection and refraction of light" and "Structure of an atom". Extract of the presentation in this regard can be seen in Appendix A. Evidence from the extract suggest that the PTPs engaged their students' prior knowledge about different concepts in physics by use of questions and activity sheets. The outcome of this mode of facilitation as observed during the instructional process for each intervention was that, learners were encouraged to: 1) give responses to questions asked by the teacher in writing and 2) reflect on the definition of reflection and refraction of light and also, recall their prior knowledge of the properties of an atom.

Apparently, the EPK also served as a pedagogical means to prepare and stimulate learners mind about the specific physics concepts that the BL and BA PhETs mimic for subsequent explorations with the PhETs during the instructional processes for both lessons.

The focus group interviews with the Learner-PTPs who witnessed the lesson by DT2 on the "Structure of the atom" provided evidence in support of this observation. One of the prospective teachers (PTP2) highlighted the significance of the recall activity which apparently, enabled learners to engage with the simulation for the first time, leading to a deeper understanding of the concept of the structure of an atom. Another prospective teacher (PTP1) emphasised the usefulness of the pre-activity. When asked to elaborate on the term "useful", as mentioned in his comment, PTP1 explained that the pre-activity facilitated their understanding of the different parts of the *BA* simulation environment and allowed them to explore it independently without explicit guidance. Specifically, the following were the comments by the Learner-PTPs in this regard when asked the question: What support structures do you believe made the simulation–based lesson effective?

> PTP2 *We realised that, based on the recall activity the teacher made us to do about the subatomic particles, we were able to play around with the simulation (hint of teachers' TPACK) for the first time and it helped us in our understanding of what an atom is.*

> PTP1 *...along the line, especially the pre-activity (referring to the introductory activity by DT2 as depicted in Figure 4) where she made us recall the properties of the sub-atomic particles like protons, electrons and neutrons was very useful.*

When PTP1 was asked to explain what he meant by the word 'useful' in his comment, he retorted as follows:

> PTP1 *It helped us to understand the simulation (referring to the BA PhET simulation environment's features) and even explore it on our own for the first time ... and she (referring to PTP4 from DT2 who taught the SBPL_2) did not have to tell us the parts; we figured it out by ourselves.*

Comments provided in this regard seem to indicate that DT2's choice to design the recall/introductory activity as a supportive structure was TPACK-informed. Apparently, this decision aimed to foster active engagement and independent exploration of the BA simulation as a means of representing and comprehending the content

Supervision of Learners' Activities

Supervision of learners' activities during the implementation of the SBPLs was also identified as one of the pedagogical support structures adopted by the PTPs to facilitate learner-centred mode of instruction. During the delivery of the SBPLs, it was observed that the PTPs who assumed the roles of teachers took keen interest in how their respective learners collaboratively worked in groups to explore the BL and BA simulation environments with the intent to answer questions on the activity sheet provided for SBPL_1 and that for SBPL_2. It seemed obvious, as observed during the instructional discourse that the adoption of supervisory roles by the teachers (PTP1 for SBPL_1 and PTP4 for SBPL_2) was aimed at identifying the challenges encountered by their respective learners in doing the activities and, to help the learners resolve their difficulties where needed. This was confirmed by one of the PTPs (i.e., PTP3) who posed as a learner during the implementation of SBPL_1. The following was the comment made by PTP3:

> *During the lesson (referring to SBPL_1), though we did almost everything, the teacher came around to supervise, which was helpful. For example, in my group (referring to DT2) he explained some points to us since we had challenges in terms of the use of the simulation.*

When asked to further explain the challenges that the teacher helped them to overcome, the following were the responses given:

> *In the course of the activity that he gave us, when we were solving, we realised that ..., we were knowledgeable about the mathematical formulae for solving it, but we found ourselves struggling to use the simulation (referring to the BL PhETs) to solve the same problem... so, we called upon him (referring to the teacher) and asked if he could help us. Then, he pointed out to us that we were using glass as the second medium of propagation instead of water; ... he then asked us to change it (hint of teacher's TPACK); in other words, he helped us to use the simulations appropriately.*

PTP4 reiterated PTP3's statement as she explained further:

> *... the activity (referring to Activity 2 of SBPL_1) that he gave us, when we were verifying Snell's law using the simulation, the answers we were getting were different from the answers we got when we solved it mathematically since we knew the formulae. We did not understand. So, we called upon the teacher for help and then he pointed out to us that we had set the second medium in the simulation environment to glass instead of water (hint of teacher's TPACK). His supervision helped us.*

Comments by PTP3 and PTP4 speak to an aspect of Activity 2 of SBPL_1 (see Appendix B). The activity required learners to set the Bending Light PhET simulation environment to specific settings (see Appendix C) to achieve the learning goals for the activity.

The setting of the second medium of light ray propagation to 'Water' instead of 'Glass' see Appendix C) led to a discrepancy between the learners' simulation results and their mathematically derived outcomes without the simulation. Consequently, the teacher's facilitative role, particularly in supervising the learners' activities, played a crucial part in enabling the effective utilisation of simulations for subject matter learning, the teacher's corrective intervention during the activity, as observed in the instructional process with the BL simulation, appears to have been deeply rooted in their developed TPACK. This could be a possible explanation for the teacher's chosen approach in addressing learners' concerns regarding their utilisation of the BL PhETs for content learning.

Fostering of Discussion Platforms

The results showed that the PTPs created authentic platforms for whole class and group discussions. This approach, apparently, also served as one of the support structures that afforded the SBPLs to be effective in advancing the learner-dominated instructional process as reported earlier. The FGI data provided evidence in this regard. When asked about the support structures they put in place during their lesson's delivery, three of the PTPs responded as follows:

> PTP4 *I believe that the inclusion of the discussion aspect in our lesson was good, so the lesson was learner-centred. The fact that they (referring to the learners who witnessed his lesson) had to work in groups, wherein they had to deliberate on their ideas and learn from their peers.*
>
> PTP2 *For me, as the teacher, I realised that the group discussions were good. It made the lesson (SBPL_2) interactive and student-centred. For example, for each of the work activities I gave them to do in the course of the instruction, they were to use the simulation to come out with the possible answers for the content question (hint of teacher's TPACK) and I observed that before they came out with an answer for the questions under each activity, they discussed to agree before they shared their final solution with the whole class.*
>
> PTP3 *Through the group discussions, they (referring to the PTPs who served as learners during his enactment of the SBPL_1) all had to come to a consensus for each simulation-based activity and then finally put something on paper (referring to the activity sheet designed by DT1); that one helped them to truly work in groups and learn the concept of refraction of light better (hint of teacher's TPACK).*

Comments by PTP2 and PTP3 seems to imply that the prospective teachers' incorporation of the discussion platforms as a pedagogical support structure was influenced by their developed TPACK. This, in turn, informed the selection and design of their lesson activities, which appeared to foster an environment that motivated learners to actively share ideas and engage in collaborative learning while using the PhETs to represent the subject matter.

Provision of Summaries

Evidence from the focus group interviews, as reported by the PTPs also identified the provision of summaries as one of the pedagogical structures that enforced the teaching with the SBPLs to be learner-centred and effective. Responses in this regard are as follows:

> PTP1 *We did all the activities by ourselves; the teacher only came in to give us a summary afterwards …*
>
> PTP3 *The fact that the lesson was student-centred, the teacher had to do a little and then, come to summarize the solution for us and we got to identify where we got the answer right or wrong in the activities. So, I think that one, he guided us.*
>
> PTP2 *I liked his summary style because it helped us to know whether what we had obtained after constructing our own knowledge with the simulation was not different from what the teacher presented in his summary.*

The responses provided by the prospective teachers suggests that the inclusion of summaries regarding the explored physics concepts during the lesson delivery created a platform for learners to address gaps in their understanding of the concepts taught using both the BL and BA simulation environments. Consistent with previous findings, the PTP's choice to incorporate summaries after each simulation-based activity during the instructional process appears to have been guided by their developed TPACK. This is affirmed by PTP4's comments during one of the focus group interview sessions following their observation of DT1's lesson on the refraction of light, which further support this result:

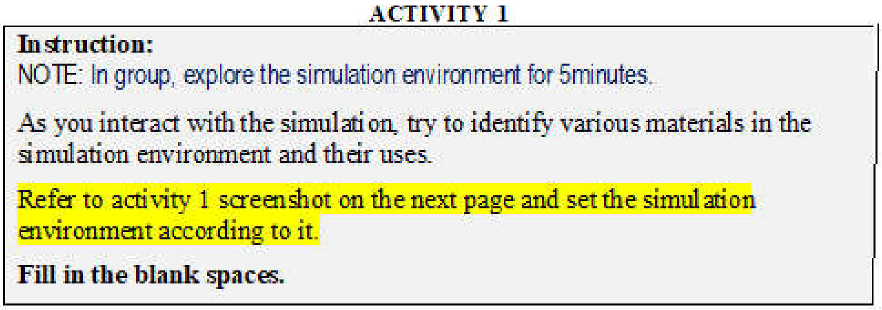
> PTP4 *After every activity, the teacher led the class to go through step by step and, gave us summaries of the concepts we explored using the simulation after each activity…*

It is important to mention that all the four facilitative strategies discussed in this study were also apparent in the lesson plan documents. Appendix D illustrates an instance where facilitative approaches were explicitly outlined in the lesson plan document for SBPL_1, as driven by the PTP's developed TPACK.

Prospective Teachers' Use of Minimal Level of Guidance

The PTPs' use of minimal level of guidance as a pedagogical support structure was realised using instructions, snapshots from the simulation environment, content-driving follow-up questions (CDFQs), and tables in the design and development of the activity sheets for SBPL_1 and SBPl_2. The instructions were designed to be specific and brief to give concise guidance to learners on each activity. For example, with the SBPL_2, Design Team, DT2 provided instructions that gave step by step directions for setting up of the simulation environment to desirable interface as well as carrying out the lesson activities. Figure 2 shows sample instructions given by DT2 on the activity sheet under Activity 1.

Figure 2 **Sample instructions as given by DT2 under Activity 1 of the SBPL_2 Activity sheet**



ACTIVITY 1

Instruction:

NOTE: In group, explore the simulation environment for 5minutes.

As you interact with the simulation, try to identify various materials in the simulation environment and their uses.

Refer to activity 1 screenshot on the next page and set the simulation environment according to it.

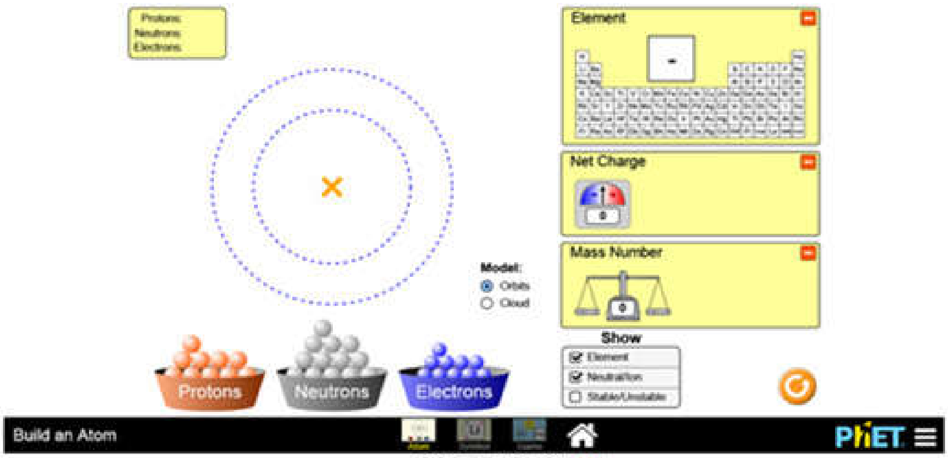
Fill in the blank spaces.

Snapshots, as used by the DTs in the development of their respective activity sheets were mostly pictures of the unexplored interface of the PhET simulation environments. These were intended to serve as the starting point for adjusting the interactive features (i.e., tabs and menus) in the simulation environments employed to help learners arrive at specific settings for the purpose of achieving the intended content goals. An example of this result was evident in the SBPL_2 activity sheet, where DT2 used a screenshot from the unexplored Build an Atom PhETs (Figure 3) to guide learners in arriving at specific settings for achieving the set learning goals. Instructions in this regard was evident in Activity 1 as shown in the areas highlighted in Figure 2.

Figure 3 Sample snapshot of the BA simulation that was used by DT2 to guide learners in achieving the set goals for Activity 1 of SBPL_2 Activity sheet

ACTIVITY 1 SCREENSHOT

Using the screenshot 'A', Set the simulation environment on your computer in a form as shown below.



SCREENSHOT 'A'

The use of content-driving follow-up questions (CDFQs) served as a guide for stimulating learners' conceptual understanding of the concepts: Reflection and refraction of light and Structure of an atom explored based on their interaction with the BL and BA PhETs (see Appendix E for excerpt). Apparently, the purpose of including CDFQs in the design of the simulation-based activity sheets was to direct the learners to: 1) explore the simulation environment given certain parameters; 2) pay attention to the feedbacks that emanate from the simulation environment upon adjusting the simulation settings or manipulating its interactive features based on parameters to be determined; and 3) make meaning of their observations of the simulation environment as well as relate them to the set goals for each activity.

Tables from the PTPs' point of view seemed crucial for providing systemic guide in the activity sheet for learners to present and organise their conceptual ideas in a specific manner as they explored the selected simulation environment (see Appendix E for excerpt). This was confirmed by one of the PTPs during the FGI where he revealed the rationale behind his team's use of a table as a support structure in the design of SBPL_1 Activity sheet:

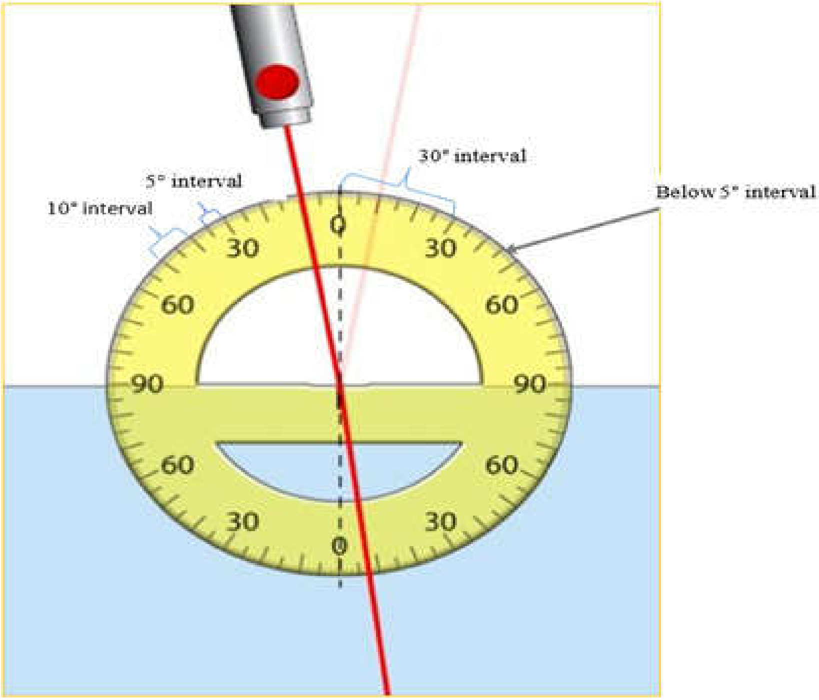
> PTP2 *Without the table (referring to table incorporated in Activity 2 of the SBPL_1 Activity sheet (i.e., Appendix B)), they (referring to the learners) might have different ways of presenting the data they had collected (referring to the feedback learners received from their interaction with the simulation environment). The aim was to get a uniform way of gathering or collecting data from the simulation.*

The prospective teachers' use of instructions, snapshots from the simulation environment, tables and CDFQs for providing minimal level of guidance in the simulation-based Activity sheets was also reflective of PTP's developed TPACK. This was observed in the Activity sheets designed for both SBPL_1 and SBPL_2 which showed evidence of how the PTP's effectively applied their knowledge and understanding of the complex interrelationships between content knowledge— CK, pedagogical knowledge—PK, and technology knowledge—TK, to create learner-centred activities that align with the lesson objectives set for both lessons using instructions, snapshots from the simulation environment, tables and CDFQs as support structures (see Appendix F for sample illustrations in this respect).

The results presented so far seem to speak to the fact that the affordances of the two PhET simulations explored and used for the design and implementation of the SBPLs by the PTPs were the underlying force that informed the PTPs' choice of pedagogical support structures as discussed herein—an indication that the potentials of the selected PhETs might have contributed to the success attained with PTP's choice of facilitative modes with the SBPLs in promoting learner-centred mode of instructional process. It is important to stress that the success attained was not without limitations, in that the selected PhET simulation environments also had some weaknesses that somewhat limited the success of instructional process. DT1 for example, identified two weakness in relation to the BL simulations: 1) weakness associated with the calibration design of the virtual protractor feature in the simulation environment and 2) weakness associated with the nature of the monochromatic ray of light emitted from the simulation's light source feature. The concerns of the PTP's who assumed the roles of learners during the enactment of the SBPL_1 about the virtual protractor were as follows:

PTP3: *is about the protractor that we used to measure the angles, we saw that the labelling or the calibration of the protractor in the simulation is not very clear. So, it was very difficult for us to measure the exact angle for the angle of incident as indicated on the activity sheet by the teacher, the angle of reflection as*

Figure 4 **Snapshot of the protractor feature of the Bending Light PhET simulation**

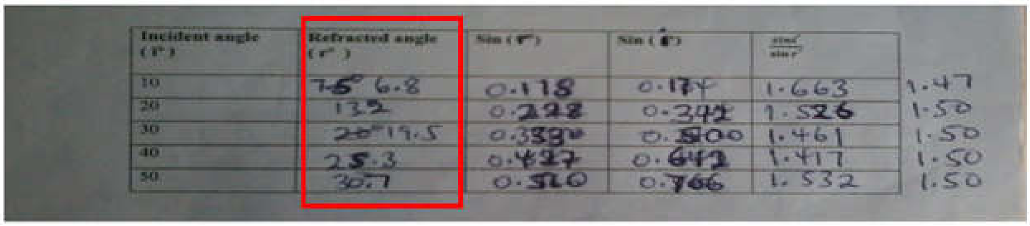


> *well as the angle of refraction using the simulation.*
>
> PTP4: *<u>the weakness is just as my colleague (referring to PTP3) has said about the protractor in the simulation</u>. So, it was difficult for us to get the exact reading on it.*

The learners in this regard had genuine concerns pertaining to the virtual protractor (see Figure 4), as this was one of shortcomings observed with the BL simulation.

The ruler grid on virtual protractor in the BL simulation has a maximum calibration limit of 90 degrees with the minimum being zero degree for each quarter division of the full circle (360 degrees). Within these limits, clear readings could be observed for angular measurement to be taken at intervals of 30, 10, and 5 degrees below which, the markings on the virtual protractor in the BL simulations are not easily accessible; especially, at intervals of 1 degree (Figure 4) where the readings on the protractor seem very blur to an observer/learner. This was the major difficulty encountered by the learners with the simulation interface. The deficiency observed with the virtual protractor seems to have encouraged learners to make fictitious approximations as they could not take accurate readings. This was confirmed by the inconsistencies observed in the values they had recorded onto their activity sheets (under Activity 2) during the enactment of SBPL_1. A comparison between the results presented by the facilitators (DT1) for the angles of refraction during the lesson and that of the learners revealed that majority of the values recorded by the learners as the refracted angle for each given incident angle (Figure 5), were either extremely below or above the values indicated by the facilitators.

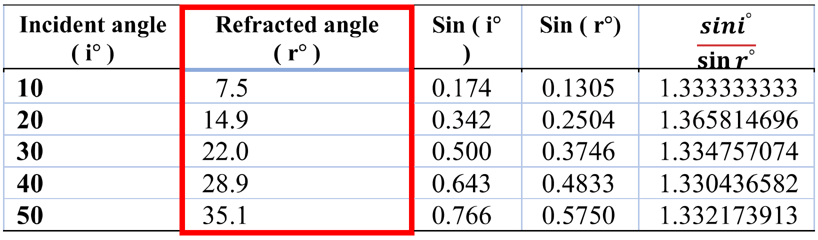
Figure 5 Activity 2 results provided by learners during the instructional process with SBPL_1



Incident angle (i°)	Refracted angle (r°)	Sin (r°)	Sin (i°)	sin i / sin r	
10	7.5° 6.8	0.118	0.174	1.663	1.47
20	13.2	0.228	0.342	1.526	1.50
30	20° 19.5	0.338	0.500	1.461	1.50
40	25.3	0.427	0.643	1.417	1.50
50	30.7	0.510	0.766	1.532	1.50

Figure 5 is a snapshot of the answers provided by the PTP's (i.e., Learners) on their activity sheets after their exploration of the simulation interface with respect to Activity 2 during the enactment of the SBPL_ 1. The area highlighted with a rectangle shows the column for the refracted angle on the learners' activity sheet where the discrepancies were observed in comparison to the facilitators' expected results. Evidently, the deepening of ink as well as the cancellations observed in the area marked with a rectangle in Figure 5 seem to communicate the possible struggles and uncertainties the learners might have encountered in coming to a consensus about the values to record per the protractor readings during the lesson. In addition, the learners' results for Activity 2 differed completely from those provided by the facilitators. Also, from Figure 5, it can be observed that the corresponding refracted angles recorded by learners for incident angles 10 and 50 degrees were 6.8 and 30.7 degrees respectively; these were not the same as that recorded by the facilitators as shown in Figure 6. Evidently, the values obtained by the learners were not close to that expected by the facilitators.

Figure 6 **Snapshot of solution to Activity 2 (Appendix BB) of SBPL_1 as provided by DT1 on their summary slide**



Incident angle (i°)	Refracted angle (r°)	Sin (i°)	Sin (r°)	$\frac{\sin i^\circ}{\sin r^\circ}$
10	7.5	0.174	0.1305	1.333333333
20	14.9	0.342	0.2504	1.365814696
30	22.0	0.500	0.3746	1.334757074
40	28.9	0.643	0.4833	1.330436582
50	35.1	0.766	0.5750	1.332173913

In relation to the second simulation-related weakness identified with the BL simulation, the following responses were gathered from PTP1 and PTP2 during the focus group discussion after their enactment of SBPL_1:

> PTP1 … *the ray emanating from the source of light of the Bending Light was relatively thick. So, even if the protractor had accurate calibrations, it would have been still a little difficult to get the exact value (referring to values obtained for the refracted angle). This made it difficult for us during the teaching since our students were struggling to take reading and we could not do anything about it.*
>
> PTP2 *Mine has to do with the ray; the fact that it is thick; so, when you put the protractor on it (referring to the ray in the simulation environment), it might fully cover two points on the protractor … and just as he said, I also think it must be very thin so that we can guide our students to read the exact mark on the protractor.*

The comments from the DT1 seem to hint that their facilitating roles as teachers were limited by the deficiencies, they had discovered in relation to the thickness of the ray from the light source feature of the BL simulation. The comments also suggest that the effectiveness of the protractor feature could be highly dependent on how thick or thin the incident, reflected or refracted rays of light appeared. In the case of the BL simulation, as pointed out by the PTPs, the ray from the light source appeared thick upon exploration of the BL simulation as depicted in Figure 5. Consequently, the ray of light whether incident, refracted or reflected does not properly align with the markings of the protractor for accurate reading to be taken. Furthermore, there is no tab on the BL simulation with a feature to help users adjust the thickness of the ray to achieve the "thin ray" that the PTPs suggest; therefore, it cannot be said for a fact that a thin ray of light emanating from the light source, when incorporated in the simulation environment would help eliminate the deficiency in the calibration design of virtual protractor as anticipated by the PTPs.

Discussion

The aim of this research was to identify and provide in-depth understanding into the specific pedagogical support structures that facilitate the implementation of simulation-based physics lessons to be successful in science classrooms for the advancement of learner-centred mode of instructional process. Based on the qualitative evidence (e.g., focus group interview, observation data, lesson artefacts designed by PTPs), the results showed that pre-service teacher participants believed that their lessons were learner-centred and that facilitative strategies such as engaging prior knowledge, supervising learner activities, fostering discussion platforms and providing summaries; which they had employed during the implementation of simulation-based physics lessons apparently, accounted for the reasons why their lessons were learner-centred. In particular, the results showed that the facilitative strategies were entrenched in the PTP's developed TPACK as well as informed and orchestrated based on the remarkable interactive affordances of the Bending Light and Build an Atom PhET simulation environment. Consequently, these modes of facilitation seem to represent the kind of pedagogical support structures that were employed by the PTPs to effectively achieve the anticipated learning outcomes set for their respective SBPLs. This finding supports the results of Bell and Smetana (2008) which showed that the effectiveness of simulations when used for instructional purposes is highly dependent on the support structures put in place. Results as presented in this regard also suggest that by use of the facilitating modes, learners were encouraged to construct their own knowledge in relation to the physics concepts taught, participate substantially throughout the instructional discourse with the SBPLs and fill in their knowledge gaps where needed. This could be explained from the view that the facilitating modes, as initiated by the PTPs were purposed to serve as "productive constraints" (Perkins et al., 2004, p. 2) for the development of learners' conceptual understanding of "Reflection and refraction of light" and "Structure of an atom" through a gradual process owing to the affordances of the BL and BA PhETs (Finkelstein et al., 2006; Clark & Mayer, 2003). This is consistent with the literature that emphasises the potentials of simulations as instructional tools for influencing teachers' adoption of pedagogical structures that are constructivist-oriented, learner-sensitive, and content-informed into their teaching practises (Hardman, 2019; Haryadi & Pujiastuti, 2020; Smetana & Bell, 2012). The success of the SBPLs as attained through the use of the facilitating modes also seems to echo that the affordances of the PhET simulation environments explored in this research stimulated the PTPs to shift their roles in the physics classroom from that of a "transmitter of knowledge to guide & facilitator of knowledge" (Majumdar, 1997, p.2) and hence, supports the finding that the simulation-based lessons were effective in promoting learner centred instructional discourse.

An additional pedagogical support component discovered in the current research pertained to the minimal level of guidance offered by the prospective teacher participants within their respective SBPLs' Activity sheets. This element of support, which was found to be reflective of their developed TPACK, seemingly contributed to the successful implementation of a learner-centred instructional approach observed in the study. These findings align with the results of Koh et al. (2013), which suggested that teachers who possess well-developed TPACK demonstrate enhanced proficiency in selecting and integrating suitable simulations, designing effective learning activities, and fostering student engagement and inquiry. Furthermore, it appears that the PTPs' adoption of minimal level of guidance was also influenced by the interactive interface of the BL and BA PhET simulation environments used in this research—supporting the statement that computer simulations "… rely on the timely guidance of a teacher" (Wieman et al., 2010, p. 225). However, the results seem not to entirely support the findings of the article: "What level(s) of guidance are needed with the PhETs for effective teaching?" by Adams et al. (2008) which suggested that "minimal guidance" implied a "Type B" level of guidance— a type of guidance that is conditioned with driving questions. This is because, the findings of this research champion minimal guidance with the PhETs to extensively involve not only driving questions (referred to as content-driving follow-up questions in this research), but also the use of instructions, snapshots from the simulation environment, and tables in the design of the activity sheets with emphasis on stimulating learners to develop mental bases that are inspired by their own thinking, questioning and personal experiences with the PhETs.

This research has implication for teacher professional training initiatives in that, the findings speak to the need for a consideration of technology-informed pedagogical support structures such as that found in this research, as key elements for shaping both prospective and in-service teachers' uptake of technology in science classrooms. This is deemed crucial for fostering enhancements in both pre-service and in-service teachers' personal and professional understanding of the various facilitative strategies that could be adopted with technology for the creation of authentic learner-dominated teaching and learning environments.

Despite the success attained with SBPLs through the PTPs' choice of pedagogical support structures which was informed by the PhETs' affordances, the research identified inherent weaknesses in the PhET which were perceived to have somewhat limited the PTPs in their respective instructional processes with the SBPLs. The results showed that the PTPs could not use their choice of pedagogical support structures to control or resolve the weaknesses identified as they seemed more of software developer-related weaknesses—making it difficult for them to guide their respective learners in using certain features of the PhETs, and consequently, seem to have hindered the learners in achieving the anticipated learning outcomes that required their uses. The results therefore suggest that the inherent weaknesses in the PhETs' environment impeded its use in the instructional process; thus, for the purpose of upgrade, it is good if further research into already existing PhET simulation environments is conducted to identify and resolve inherent weaknesses which do not represent the subject matter accurately. For example, with the Bending Light PhET simulation, the need for developers of the PhETs to consider: a) modifying the calibration design of the virtual protractor feature to allow for clear and accurate readings; especially at intervals below 5 degree where the readings on the protractor currently seem very blur to an observer/learner; and b) including an additional interactive tab or menu in the Bending Light simulation interface is recommended to help users/learners adjust the thickness of the monochromatic ray in order to facilitate accurate readings with the virtual protractor.

Conclusion

The study examined the pedagogical practises of four prospective teachers through a professional development framework, as reflected in their design, development, and implementation of PhET simulation-based physics lessons, using the TPACK framework as a theoretical lens. The prospective teacher participants enacted their lessons among themselves in two rounds of microteaching sessions using Bending Light and Build an Atom PhET simulation environments. Findings as discussed herein advocate that teachers' roles in science classrooms which are entrenched in the provision of minimal level of guidance and facilitative modes such engaging prior knowledge, supervising learner activities, fostering discussion platforms, and providing summaries are key ingredients for effective implementation of technology-based innovations that place learners at the centre of the instructional discourse; hence, they represent the needed pedagogical support structures that drive the instructional processes with technology (e.g., PhET simulations) to be learner-focused. It is important to stress that central to the success attained with the simulation-based lessons in the context of this research, was the prospective teachers' enhanced proficiency in integrating selected simulations and designing effective learning activities, which was reflective of their developed TPACK as well as the content-sensitive and interactive affordances of the PhET simulations, which served as the driving forces for bringing into action the pedagogical support structures that propelled the instructional process with PhETs to be learner-centred; irrespective of its inherent weaknesses as a technological tool.

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Appendices

Appendix A Excerpts of introductory slide during the implementation of SBPL_2 and SBPL_1 with the corresponding review activity sheet for SBPL_2

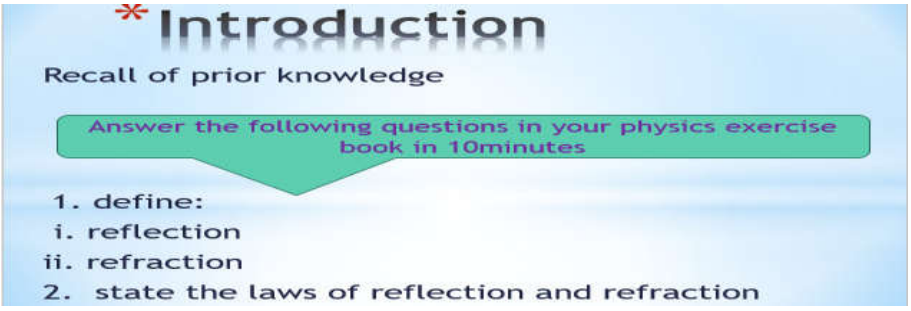
- (15minutes)
- STUDENTS' PREVIOUS KNOWLEDGE
- REVIEW QUESTIONS (ON STUDENT PREVIOUS KNOWLEDGE).docx

REVIEW QUESTIONS ON STUDENTS' PREVIOUS KNOWLEDGE

Instruction: Based on our previous lesson, carefully read, and answer the following questions by circling and filling in the blank spaces.

DURATION: 15 minutes

1. Which of the following statements is true about an atom?
    - A. If an atom becomes electrically charged by gaining or losing one or more electrons, it becomes a molecule.
    - B. If an atom gains electron, it has a positive charge.
    - C. Atom is the smallest particle into which an element can be divided without losing its chemical properties.
    - D. Hydrogen is example of an atom.
2. The following statements describe the properties of the sub-atomic particles. Fill in the blank spaces with the particle that best fit the description.
    - A. They are almost massless but carry negative charges as they orbit the nucleus…………………………………………
    - B. They are found in the nucleus of an atom and are electrically neutral but made up of other elementary particles………………………………………
    - C. They are heavier building block of an atom and are positively charged…………………………
3. Draw the structure of an atom and identify the sub-atomic particles.



* Introduction

Recall of prior knowledge

Answer the following questions in your physics exercise book in 10minutes

1. define:
i. reflection
ii. refraction
2. state the laws of reflection and refraction

Appendix B Excerpt of Activity 2 of the SBPL_1 Activity sheet as designed by DT1

ACTIVITY 2

Verification of Snell's law (laws of refraction) (30minutes)

TPACK

This activity is aimed at guiding you to understand and verify Snell's law in different media.

In this activity, you are required to use the simulation environment to help you find the refractive index of water by performing the tasks below. Referring to the snapshot above in activity 1:

- With the help of the protractor, set the angle of incidence (i°) to 10° measure and record the corresponding angle of refraction.
- Repeat the above step with i° = 20, 30, 40 and 50 and measure the corresponding angles of refraction for each value
- Compute and record the sine of the angles of incidence and refraction in the activity 2 sheet.
- Complete the table by using your calculators to do the necessary computations.

Incident angle (i°)	Refracted angle (r°)	Sin (i°)	Sin (r°)	$\frac{\sin i^{\circ}}{\sin r^{\circ}}$
10				
20				
30				
40				
50				

Answer the following questions using the values obtained from the simulation.

1. Determine the average of the values of $\frac{\sin i^{\circ}}{\sin r^{\circ}}$ in 3 decimal places.

…………………………………………………………………………………

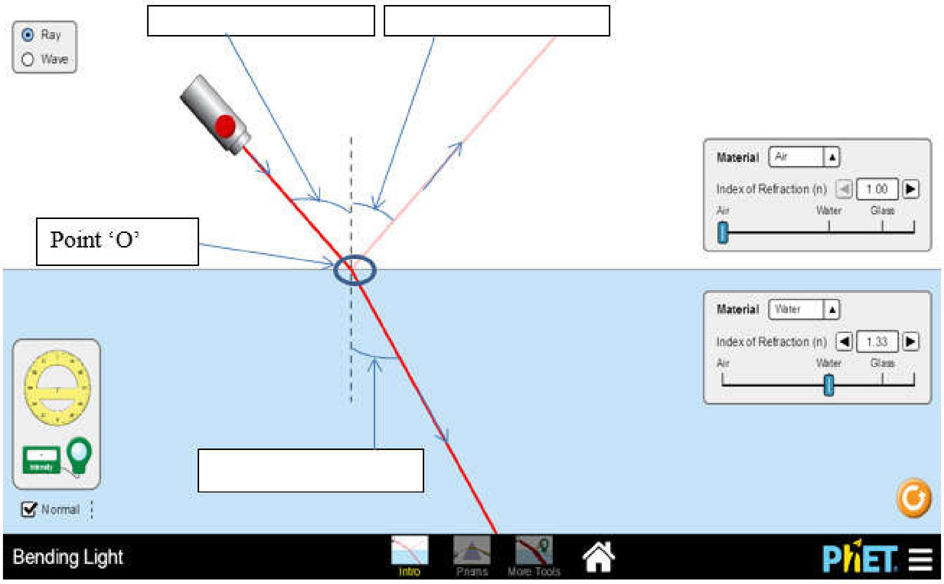
2. What does the average you found in question 1 above represent?

Appendix C Snapshot of specific setting of the BL PhET environment explored by DT1 in their design of lesson Activity 1 for SBPL_1

Instruction for carrying out the activity

- Set the simulation environment as shown in the snapshot below

Note: label the parts indicated by boxes in the snapshot below.



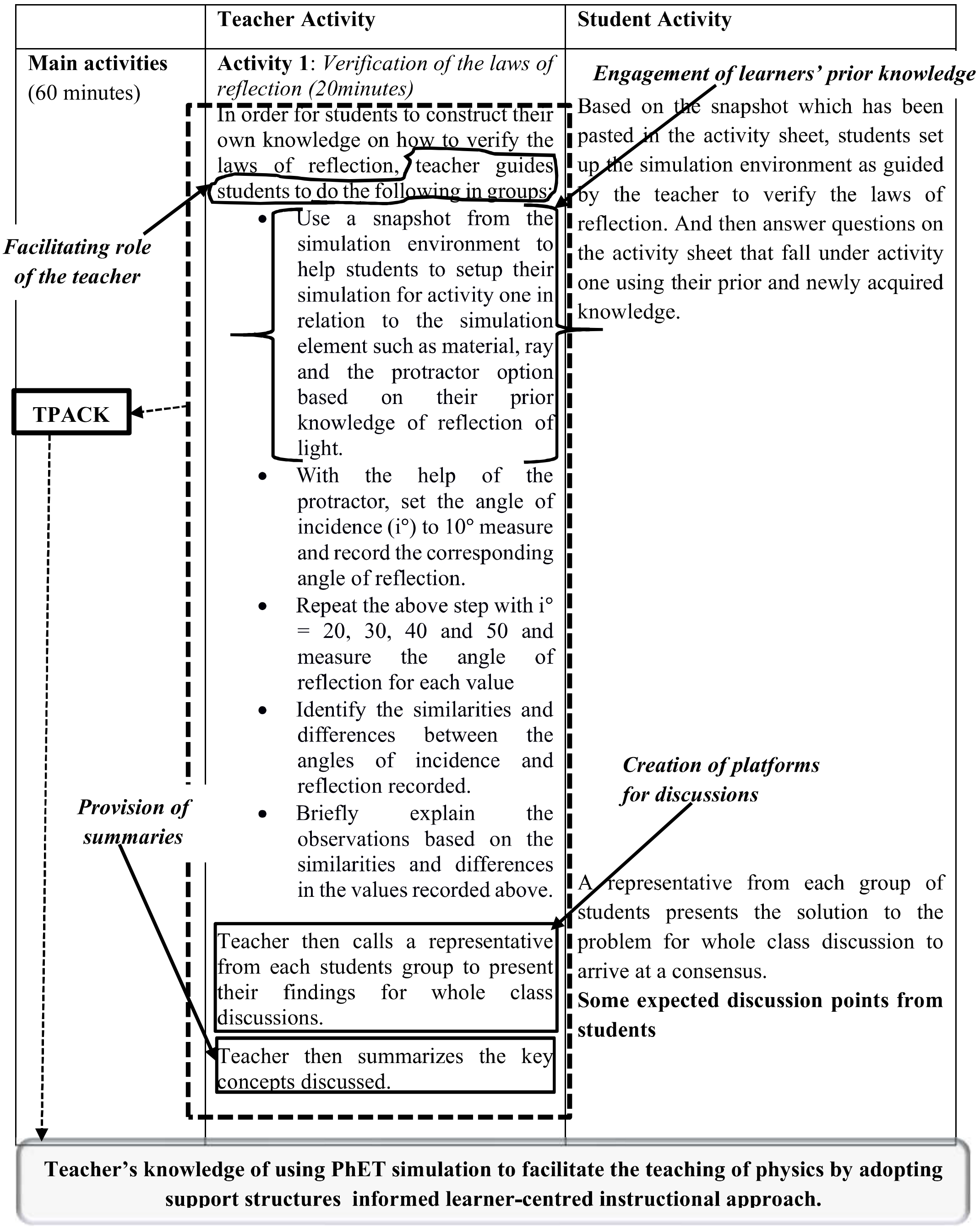
● Ray
○ Wave

Material: Air
Index of Refraction (n): 1.00

Material: Water
Index of Refraction (n): 1.33

☑ Normal

Appendix D Illustration of facilitative modes as depicted in the SBPL_1 lesson plan document based on the PTP's developed TPACK



	Teacher Activity	**Student Activity**
Main activities (60 minutes)	**Activity 1**: *Verification of the laws of reflection (20minutes)* In order for students to construct their own knowledge on how to verify the laws of reflection, teacher guides students to do the following in groups: • Use a snapshot from the simulation environment to help students to setup their simulation for activity one in relation to the simulation element such as material, ray and the protractor option based on their prior knowledge of reflection of light. • With the help of the protractor, set the angle of incidence (i°) to 10° measure and record the corresponding angle of reflection. • Repeat the above step with i° = 20, 30, 40 and 50 and measure the angle of reflection for each value • Identify the similarities and differences between the angles of incidence and reflection recorded. • Briefly explain the observations based on the similarities and differences in the values recorded above. Teacher then calls a representative from each students group to present their findings for whole class discussions. Teacher then summarizes the key concepts discussed.	Based on the snapshot which has been pasted in the activity sheet, students set up the simulation environment as guided by the teacher to verify the laws of reflection. And then answer questions on the activity sheet that fall under activity one using their prior and newly acquired knowledge. A representative from each group of students presents the solution to the problem for whole class discussion to arrive at a consensus. **Some expected discussion points from students**

Teacher's knowledge of using PhET simulation to facilitate the teaching of physics by adopting support structures informed learner-centred instructional approach.

Appendix E *Excerpt of Activity 2 of the SBPL_2 Activity sheet showing how DT2 made use of tables and CDFQs to provide minimal level of guidance to learners*

ACTIVITY 2

Instruction: Carefully read and follow the steps below to answer question 7 to 13.

In the simulation environment:

- close the simulation and reopen it.
- on the net charge and mass number bar, which is below the element bar, click on the positive sign to change to negative sign.
- use the protons (p) to find the mass number of each element by dragging one proton at a time. NOTE: Mass number = proton (p) + neutron (n) number.

Use the number of protons to verify the elements.

Use of Tables

ELEMENT	PROTON(P)	NEUTRON(N)	P+N	NET CHARGE
7. Helium	____________	2	____________	____________
8. Beryllium	____________	4	____________	____________
9. Carbon	____________	6	____________	____________
10. Nitrogen	____________	7	____________	____________
11. Neon	____________	10	____________	____________

12. What do you notice of the element as new proton is added into the atom? Briefly explain your answer.

…………………………………………………………………………………………

…………………………………………………………………………………………

……………………

Use of CDFQs

13. Start adding electrons into the atom in the simulation environment one at a time and observe the net charge reading.

What happens to the value of the net charge as more electrons are added? Briefly explain your observation.

……………………………………………………………………………………………

Appendix F Illustration of TPACK as applied and reflected in DT1's use of various elements of minimal level of guidance in the design of Activity 1 within SBPL_1's Activity sheet

TPACK informing the use of instructions, snapshot, table and CDFQ, as a guide

Snapshot of BL PhET; TK

ACTIVITY 1: Verification of the laws of reflection

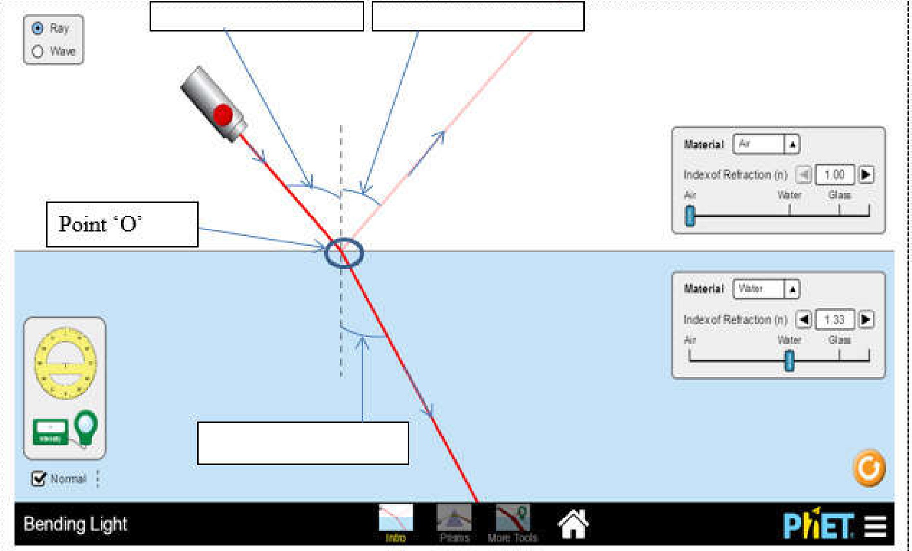
This activity is aimed at helping students verify the laws of reflection.

Instructions; TPK

Instruction for carrying out the activity

- Set the simulation environment as shown in the snapshot below.

Note: label the parts indicated by boxes in the snapshot below.



- Using your previous knowledge, as well as the simulation environment, identify the incident ray, the reflected ray and the normal

Instructions; TPACK

- With the help of the protractor, set the angle of incidence (i°) to 10°
- Measure and record the corresponding angle of reflection in the table below.
- Repeat the above step with i° = 20, 30, 40 and 50 and measure and record the corresponding angle of reflection for each value of i°

Incident angle	10°	20°	30°	40°	50°
Reflected angle					

1. With reference to point 'O' from the snapshot above, briefly explain your observation in relation to the first law of reflection.

Instructions, Table, and CDFQ; TPACK