Contemporary Mathematics and Science Education
2024, 5(2), ep24009
ISSN 2634-4076 (Online)
https://www.conmaths.com/

Research Article

OPEN ACCESS

Technology integration in science classrooms: Empowering student teachers for improved physics teaching with simulations

Elizabeth Darko Agyei [1]*, Loyiso C. Jita [2], Thuthukile Jita [3]

[1] Department of Science Education, University of Cape Coast, Cape Coast, GHANA
[2] School of Mathematics, Natural Sciences and Technology Education, University of the Free State, Bloemfontein, SOUTH AFRICA
[3] School of Education Studies, University of the Free State, Bloemfontein, SOUTH AFRICA
***Corresponding Author:** elizabeth.cornah@ucc.edu.gh

Citation: Agyei, E. D., Jita, L. C., & Jita, T. (2024). Technology integration in science classrooms: Empowering student teachers for improved physics teaching with simulations. *Contemporary Mathematics and Science Education*, 5(2), ep24009. https://doi.org/10.30935/conmaths/14688

ABSTRACT

This study employed a descriptive case study design to examine the integration of technology in science education, focusing on the professional development of student teachers in Ghana. Using the technological pedagogical and content knowledge (TPACK) framework as a theoretical lens, the study aimed to address the gaps in existing teacher education programs. Through a technology integration training workshop, the progress of four student teachers in developing their competencies for integrating technology into the teaching of high school physics using simulations was tracked and examined. Drawing on a combination of quantitative (survey) and qualitative data (focus group discussions, semi-structured interviews, observations, and lesson artefacts) sources, findings revealed that the student teachers improved their teaching with technology, which was evident in their developed TPACK, improved content knowledge and developed competencies in the exploration of Physics Education Technology simulation environments. These outcomes suggest a transformative shift in student teacher's teaching approaches, transitioning from a teacher-centered paradigm to a learner-centered one, particularly within the context of simulation environments. Despite initial challenges associated with insufficient content knowledge, establishment of relationships among physics content, teaching strategies and the identified affordances of the simulation environment as well as the shift from traditional to learner-centered approach, the study underscores the pivotal role played by the professional training arrangement implemented for the research.

Keywords: physics, technology-oriented competencies, simulations, student teachers

Received: 05 Feb. 2024 ◆ Accepted: 13 May 2024

INTRODUCTION

The integration of technology has become imperative for effective teaching and learning in the dynamic landscape of education, demanding that teachers are trained to possess technology-oriented skills to cater for the requirements of modern classrooms. Despite the global positive perception by teacher educators about the importance of technology uses in education, literature (e.g., Lim et al., 2011) highlights gaps in the existing prospective teacher education programs that are adopted by teacher training institutions. Apparently, most of the education courses do not prepare teachers for theory-driven and content-sensitive technology-mediated teaching and learning instructional processes (Lawless & Pellegrino, 2007).

In the context of Ghana, different non technology-based teaching approaches have been proposed for training teacher trainees in Ghana. A reflection by Akyeampong (2003) on possible teaching approaches for teaching the content of various subjects as mentioned in Asare and Nti (2014, p. 5) suggests that "transmission of knowledge"; "question and answer approach"; "learner-centered teaching" and others like problem solving, brainstorming among others, are the teaching methods recommended for training teacher trainees in Ghana. However, the dominant pedagogical approach remains one, where trainees are largely regarded as 'empty vessels' with little knowledge or experience of teaching (Lewin & Stuart, 2003, p. 171)–suggesting that teacher-centered approach is the main teaching approach being adopted in Ghana to train teachers. This seems to be the basis for the non-interactive and "chalk and talk" (Ottevanger et al., 2007) teaching methods being adopted for the teaching of physics in the senior high schools (SHSs) in Ghana and perhaps, one of the major causes of the poor performance recorded for physics in recent years at SHS level in Ghana and also, a possible reason for the dwindling interest in the subject (Buabeng & Ntow, 2010; Buabeng et al., 2014; Darko Agyei et al., 2019; Yawo, 2020).

A shift from the teacher-dominated to a learner-centered approach is what literature (Voogt, 2003) recommends, however, not much

This study is derived from the first author's PhD thesis.

attention has been paid to determine how this shift in paradigm could be effectively realized and understood for physics teaching at SHS level in Ghana. These arguments advocate potential gaps in the teacher education programs being rolled out to train prospective (student) science teachers in Ghana; hence, the need for a professional development framework with components that would readily equip pre-service and in-service teachers with the required technology-oriented knowledge and skills for effective instructional process with technology as well as assist teachers to develop understanding into how technology can be used to effectively transform the teaching and learning of specific contents informed by theory.

Various studies, including those by Chai et al. (2013), Prabawa (2017), and Voogt and Mckenney (2016) highlight the significance of technology-mediated instruction and learning in teacher education. Technological pedagogical and content knowledge (TPACK) by Mishra and Koehler (2006) merges as a pivotal framework in these studies, serving as a guide for research into teachers' utilization of technology, offering a foundational perspective on considering technology as an integral partner, and providing essential insights into teachers' knowledge for effectively incorporating technology into lessons. Findings in this regard appear to champion TPACK as a potential theoretical framework through which the progression of teachers in acquiring technology-oriented competencies for learner-focused instructional process could be examined and understood. Advancing student teachers' competencies in technology use for effective instructional process in science classrooms requires specific strategies for successful implementation process (Agyei & Voogt, 2014; Goktas et al., 2008; Tondeur et al., 2018).

Different strategies have been advocated for the development of student teachers' competencies for technology integration (Mouza et al., 2014; Tondeur, 2018). Tondeur (2018, p. 2) for example, highlighted strategies such as "using teacher educators as role models", "reflecting on the role of technology in education"; "learning how to use technology by design"; "collaboration with peers"; "scaffolding authentic technology experiences"; and "providing continuous feedback" to be effective for equipping student teachers to adequately use technology in their teaching practices. Tondeur (2018) further explained that for effective implementation of these strategies, technology integration must be incorporated as a systemic and systematic process that leverages on the collaborative and team spirit efforts of teachers as reflected in teacher design teams (Agyei, 2012; Kafyulilo et al., 2015; Voogt et al., 2016). The concept of teacher design team is thus advocated as the platform by which all Tondeur's (2018) six strategies are put into action for the success of technology integration.

Literature as presented herein suggests a possible roadmap and also, gives a hint for possible professional development components to be considered for training student teachers to use technology in the realm of science education, however, not much studies have been done to delineate a mechanism that tracks and understands how student teachers improve their teaching with technology under the auspices of these strategies as entrenched in a professional training workshop that is theory-driven for the specific case of science (physics) education in Ghana. It is against this background that the present study, through a technology integration training workshop (TITW) informed by Tondeur's (2018) proposed strategies, tracked, and examined the progress of four student teachers in developing their competencies for integrating technology into the teaching high school physics using TPACK framework as a lens. This was aimed at providing an explanation into how and why improvements in teaching using a technological tool such as simulations through implementation processes are possible. In particular, the study sought to address the research question: "How can the improvements in teaching using technology (simulations) be understood?"

SIMULATIONS IN SCIENCE CLASSROOMS

The incorporation of simulations in science classrooms has gained considerable attention as a powerful strategy to enhance teaching and learning. Drawing insights from multiple studies, including Agyei and Agyei (2021a), Bell and Smetana (2008), Donnelly et al. (2011), Majumdar (1997), Webb and Cox (2004), and Wieman et al. (2010), the literature emphasize the transformative impact of simulations on science education. Research works by Agyei and Agyei (2021) and Bell and Smetana's (2008), for instance, highlight the substantial contribution of simulations to students conceptual understanding, emphasizing the visualization and manipulation of complex scientific phenomena. Wieman et al. (2010) further support the idea that simulations facilitate active learning and inquiry-based approaches, creating a safe space for students to experiment and learn through trial and error. Donnelly et al. (2011) provide insights into the alignment of well-designed simulations with constructivist principles, promoting critical thinking skills and contextualized exploration of scientific concepts. Webb and Cox's (2004) work emphasize the role of simulations in providing a dynamic and interactive learning environment that transcends traditional instructional methods. Additionally, Majumdar's (1997) findings contribute to the broader understanding of simulations as a tool that not only improves conceptual understanding but also positively influences student engagement. As teachers seek innovative approaches, the cumulative evidence from these studies underlines the potential of simulations to transform science classrooms, offering a pathway to more effective and engaging science education.

In the context of this research, the specific category of simulations explored was Physics Education Technology (PhET) simulations (Finkelstein et al., 2006) developed at the University of Colorado, Boulder. PhET simulations are characterized as stand-alone content-specific simulations designed to represent and facilitate enhancements in the teaching and learning of not only physics, but in recent times, mathematics and other sciences like biology and chemistry. Among the sciences, they are considered as one of the popular technological instructional tools since they are free; users need not pay any amount to enjoy its use. Furthermore, they are java-based animations with remarkable features that allow users to run online and download from the website (http://phet.colorado.edu) to be used offline; thus, they are not limited to internet access. Technologically, PhETs provide dynamic and interactive interfaces that enable students to manipulate variables and conduct virtual experiments, fostering engagement and exploration (Finkelstein et al., 2006). Moreover, they offer real-time feedback and visual representations of abstract concepts, facilitating deeper conceptual understanding (Redish, 2003). Pedagogically, PhET simulations align with constructivist principles by promoting inquiry-based learning, where students actively engage in scientific inquiry and hypothesis testing (Donnelly et al., 2011; Price et al., 2019). They also champion collaborative learning approach, allowing students to work together to solve problems and construct knowledge collaboratively

(Sang et al., 2017). By these affordances of PhETs, teachers are empowered in that they are provided with innovative tools to facilitate the creation of dynamic and interactive lessons, thereby enhancing their pedagogical practices and consequently, promoting student-centered instruction. The characteristics discussed herein situate PhET simulations as potential catalyst for developing student teachers' technology-oriented competencies for realizing improvement in physics teaching. Consequently, informing PhETs' use as technological instructional tool for the current study; serving as an appropriate and feasible tool for teaching physics in the Ghanaian science classroom context. Subsequently, we use "PhET simulations" and "simulations" interchangeably.

THEORETICAL BASIS

TPACK framework (Mishra & Koehler, 2006) constituting seven different knowledge domains (see **Figure 1**): technology knowledge (TK), pedagogical knowledge (PK), content knowledge (CK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), pedagogical content knowledge (PCK), and TPACK, has been recognized by educational researchers (Agyei & Voogt, 2012; Harris et al., 2009; Koehler et al., 2013; Shinas et al., 2013) for its potential for providing researchers, teachers, and educators with a roadmap to theorize how technology can be integrated to make teaching and learning more effective (Archambault & Barnett, 2010).

According to Chai et al. (2010), there are two viewpoints when it comes to the epistemological nature of TPACK framework. A transformative viewpoint, which positions TPACK as a combination of TK, PK, and CK in a manner that their influences on each other cannot be detached (Gess-Newsome, 1999)–recognizing TPACK as a unique body of knowledge (Harris et al., 2009). The second viewpoint is the integrative model, which does not recognize TPACK as a unique body of knowledge (Angeli & Valanides, 2009), but instead describes TPACK as a simple combination of TK, PK, and CK brought into light only during the teaching process (Chai et al., 2010). This seems to suggest that how the teacher demonstrates or applies these three knowledge bases in the classroom is crucial for bringing into action the interconnections that exist between the three knowledge domains as depicted in **Figure 1**.

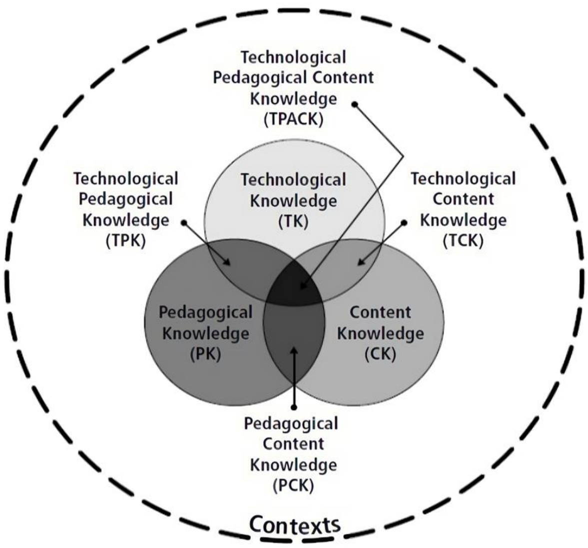


Figure 1. TPACK model (Koehler et al., 2013)

In this study, TPACK framework was considered more suitable for exploring student teachers' competencies in using technology for effective teaching of high school physics using PhET simulations as the technological tool. The focus here was to track and understand how the student teachers' TPACK could be developed and applied through a professional training arrangement. In addition, how the combined effect of three knowledge domains (i.e., TK, PK, and CK) unfolded in the teaching try-out sessions was key to explaining how teaching improved with technology. As a result, we do not choose a position on the two perspectives about TPACK framework; instead, we view each description as pertinent to accomplishing the goals established for the current study, which focuses on the knowledge domains, where technology is used (i.e., TK, TPK, TCK, and TPACK).

TPACK lays much emphasis on "context". This was the later addition to TPACK model in 2008, which was based on the idea that technology-enhanced instruction is never isolated from its educational setting (Fisser et al., 2015). Literature (George, 2014; Rosenberg & Koehler, 2014) highlights that "context" is the part of TPACK framework that is often not attended to and even when considered by researchers, the context is rarely discussed. Apparently, the importance of the context and its irrefutable weight on how TPACK could be adapted, is still in the realization stage. According to Kelly (2008), context includes a wide range of elements, including the physical aspects of the classroom, the demographics of students and teachers, the teachers' knowledge, abilities, and dispositions, and the students' and teachers' cognitive, experiential, physical, social, and psychological qualities. In Koehler et al.'s (2012) view, it is the synergetic effect of these elements, which ensures uniqueness of the grounds on which TPACK model is adapted. This seems to imply that TPACK as a framework goes beyond considering the three knowledge domains in isolation and emphasizing the kind of intersections and relationships that must exist between and among the three knowledge domains, to appreciate the unique contexts in which the interconnections that exist, though complex, could be situated for effective technology integration in teaching. It is against this background that TPACK was contextualized in this research as the framework for tracking and explaining how student teachers develop technology-oriented competencies. In particular, the technology that was learned and explored by the participants was PhET simulations and was chosen on the basis that; it is readily available; user friendly; has the potential to be sustained in Ghana; affords interactivity, enhances the efforts of a teacher (Agyei & Agyei, 2021b; Wieman, et al., 2010); and provokes independent and critical thinking. The content was physics, which was also the student teachers' major teaching subject. For the pedagogical component in TPACK model, the study adopted an activity-based approach leveraging on the affordances of PhET in representing selected physics content. Informed by context as explained herein, the technology constructs of TPACK framework were operationalized, as follows:

- TK–knowledge of the operational affordances of simulations.
- TPK–knowledge of how to use simulations through activity-based form of inquiry.
- TCK–knowledge of using simulations to represent concepts in physics.
- TPACK–knowledge of using simulations to facilitate activity-based teaching of physics.

Table 1. Components of TITW & training activities considered

Components of TITW	Training activities	Alignment to Tondeur (2018)'s strategies
Introduction to foundational theories or oncepts underpinning PhET simulations integration.	• Presentations/discussions on TPACK framework & concept of teacher design team approach. • Coding of sample TPACK-based lesson artefacts by participants in teams. • Discussions on different physics classroom context for TPACK application.	• Reflecting on role of technology in education. • Collaboration with peers. • Reflecting on role of technology in education.
Learning how to use PhET simulations by design.	• Introduction to Microsoft PowerPoint presentation software as an instructional delivery tool & PhET simulations. • Scaffolding authentic PhETs experiences in teams in relation to selected physics topics. • Demonstration of exemplary SOPLs by researchers & discussion. • Development of SOPLs by student teacher participants in design teams.	• Learning how to use technology by design. • Scaffolding authentic technology experiences/collaboration with peers. • Using teacher educators as role models. • Learning how to use technology by design/collaboration with peers.
Implementation of SOPLs	• Enactment of SOPLs to colleagues/course mate peers/researchers	• Learning how to use technology by design/providing continuous feedback.

Table 2. Overview of simulation environments explored by student teachers in teams during TITW

PhET simulation environment	Content	Design teams
Hooke's law (HL)	Deformation of solids	Team 1
Forces & motion: Basics (friction) (FM-BF)	Frictional force	Team 2
Resistance in a wire (RW)	Resistance	Team 2
States of matter (SM)	States of matter	Team 1

TRAINING ARRANGEMENTS & ACTIVITIES

A 2-week TITW was organized for four student teachers who were involved in the study. The training program consisted of three components; component one: Introduction to foundational theories/concepts underpinning PhET simulation integration, component two: Learning how to use PhET simulation by design, and component three: Implementation of simulation-oriented physics lessons (SOPLs). Component one formed the basis for the other two components of TITW and hence, served as the foundation for the whole training process, during which a comprehensive exploration of TPACK model and its nature was conducted. The intention was to help the student teachers reflect on the needed TPACK required for designing and implementing SOPLs. Component two was purposed to guide the student teachers through exploratory hand-on exercises to discover the affordances of PhET simulation environments in representing the subject matter. This helped them to design their own lesson using selected PhET simulations in design teams of two members each. Component three was intended to provide authentic platform for the student teachers to implement their designed SOPLs in their design teams. This, they did through teaching try-outs first among themselves and second, among their course mate peers based on their experiences and knowledge acquired through the whole training process. Detailed information on the training activities for each component of TITW and their respective alignment to Tondeur (2018)'s proposed strategies for the development of student teachers' technology integration competencies are presented in **Table 1**.

The researcher's (first author) role during the training program was mainly that of a facilitator. She also developed the two exemplary SOPLs (appraised by the second and third authors) that were used as part of the training resources during TITW.

PhET simulation environments (downloaded from PhET website: https://phet.colorado.edu/), which the design teams explored and integrated into their physics lesson designs are shown in **Table 2**. In all, two lessons on selected physics topics were designed by the teams.

RESEARCH METHODS

Research Design

Using a descriptive case study design, both quantitative (survey) and qualitative (focus group discussions [FGDs], semi-structured interviews, observation [researchers' logbook], and lesson artefacts) data evidence were employed in this study to explain why and how teaching improved using PhET simulations. It is crucial to emphasize that the quantitative evidence collected was not intended for statistical generalization, instead, its purpose was to contribute to a comprehensive understanding of improvements in teaching using technology.

Participants

Four third-year student teachers of the Bachelor of Education program with specialization in science at one of the public universities in Ghana participated in the current study. The students consisting of one female and three males were aged between 19 and 28 with an average age of nearly 23 years. Purposive sampling was employed to select the four student teacher participants based on the following criteria:

(a) availability,

(b) major teaching subject,

(c) commitment, and

(d) seriousness.

The student teachers: STDT1A and STDT1B; and STDT2A and STDT2B (pseudonyms) worked in design teams: STDT1 (team 1) and STDT2 (team 2), respectively to develop and implement PhET SOPLs. Nine other student teachers (referred to as course mate peers) drawn from the same institution and enrolled in the same program also volunteered to be part of the study. Their role primarily involved assuming the position of learners–mimicking the characteristics of SHS students exclusively during the teaching trial sessions within the framework of TITW.

Instruments

Survey, FGDs, semi-structured interviews, observations (using researchers' logbook), lesson artefacts and were the data source for this study. These data sources were employed to ensure triangulation, facilitating both explanation and a comprehensive understanding of how student teachers in the context of this study, developed their competencies for integrating simulations into their teaching practices.

TPACK self-assessment instrument, comprising 38 items under seven constructs: TK, PK, CK, PCK, TCK, TPK, and TPACK was adapted from Schmidt et al. (2009a) with a Cronbach's alpha (α) reliability estimate ranging from 0.75 to 0.93 (Schmidt et al., 2009a) and a construct validity score of 7.88 (Schmidt et al., 2009b) for five of the seven constructs. The questionnaire was specifically modified to assess student teachers developed TPACK for integrating simulations into physics teaching. Two experts in the field of physics education and educational technology were consulted to review the modified instrument and provide feedback on its relevance and comprehensiveness. To assess the reliability of the items, α was computed (TK: seven items; α= 0.91; PK: seven items, α= 0.84; CK: four items, α= 0.78; PCK: five items, α=0.87; TCK: three items, α= 0.81; TPK: seven items, α= 0.83; and TPACK: five items, α=0.88) and found to be reliable (according to DeVellis, 1991) for all the seven constructs. The instrument was administered before and after TITW.

FGDs session was conducted with the participants following their first teaching try-outs among themselves, where both design teams taught with their first SOPLs. This was planned to facilitate reflections on the appropriateness of the choice of simulation environment in representing the selected topic. Discussions in this regard were aimed at identifying both the weaknesses and strengths of SOPLs, eliciting suggestions for improvement. Additionally, the essence of TITW, specifically the first component, was also discussed with feedback utilized to refine their designs. All discussions were audio-recorded.

A semi-structured interview guide was also used to collect data in this study. Interviews with the STDTs in this regard were conducted after the second teaching try-out session, where they taught their revised SOPLs among their course mate peers, based on feedback from FGD. The interview guide (see **Figure A3** in **Appendix**), which was adapted from Agyei (2012) covered themes such as personal information, lesson planning and preparation, in-lesson activities, and post-review of teaching. These collectively provided valuable insights into the student teachers' development of technology-oriented competencies and the efficacy of the training. The interview guide was given to experts in the field of technology education to review its content. This was purposed to ensure that it accurately captures the key aspects of the student teachers' development of technology-oriented competencies and the efficacy of TITW.

For credibility, iterative questions were used as a strategy during the interview sessions of the study to extract similar data from the participants by rephrasing the questions previously asked during the interview. This was a method adopted to check contradictory statements as well as falsehoods in the information given.

A researchers' logbook was employed to record and document detailed observations made throughout the training process, with particular emphasis on the teaching trial sessions, wherein participants were engaged in instructional activities both among themselves and their course mate peers.

The study also utilized lesson artefacts (e.g., lesson plans, presentation slides and activity sheets) created by the student teachers as additional sources of data. These were collected during TITW.

Data Analysis

Responses to TPACK questionnaires were rated using a Likert scale from strongly disagree (one) to strongly agree (five). A mean score of three and above signified a positive and favorable opinion, while a score below three indicated a negative perspective in the teachers' responses. Data derived from the semi-structured interviews and FGDs underwent transcription from audio to text and were subjected to analysis using data reduction technique (Miles & Huberman, 1994). This involved identifying themes and patterns aligned with TPACK framework. In addition, document analysis was employed to examine and attribute meanings to the text-based data extracted from the participants' lesson artefacts, such as activity sheets, lesson plans, and MS PowerPoint presentation slides. Special attention was given to the designed lesson activities derived from the selected PhET simulations.

RESULTS

Three themes emerged from both the quantitative and qualitative data to explain how and why improvements in teaching using various PhET simulation environments through implementation processes, as situated in TITW are possible. These included: student teachers' developed TPACK, student teacher's improved CK, and student teachers' developed competencies in the exploration of PhET simulation environments.

Student Teachers' Developed TPACK

Results showed that the student teachers improved their teaching with technology because they developed their knowledge and skills (TPACK) for integrating PhET simulations into the teaching of high school physics. The quantitative data underscores this improvement with **Table 3** offering a summary of the outcomes derived from the pre-post survey. These results are delineated based on the self-efficacy expressions of four teachers across various TPACK constructs.

Table 3. Results for pre- & post-survey mean score responses for TPACK sub-scales

	STDT1A			STDT1B			STDT2A			STDT2B		
	Pre	Post	Difference	Pre	Post	Difference	Pre	Post	Difference	Pre	Post	Difference
TK	3.57	3.97	0.40	2.29	4.71	2.42	3.71	4.87	1.16	2.86	3.43	0.57
PK	3.86	3.57	-0.29	3.43	3.86	0.43	3.86	3.71	-0.15	3.86	3.42	-0.44
CK	3.80	4.00	0.40	2.20	4.60	2.40	4.00	4.60	0.60	4.00	4.40	0.40
PCK	3.80	4.00	0.20	2.40	4.80	2.40	3.20	4.00	0.38	4.00	4.20	0.20
TCK	3.67	4.00	0.33	2.33	4.67	3.34	3.00	4.00	1.00	3.00	4.00	1.00
TPK	3.57	4.20	0.43	2.42	4.86	2.44	3.57	4.86	1.29	3.29	4.00	0.71
TPACK	3.40	4.20	0.80	2.00	4.80	2.80	3.40	5.00	1.60	2.80	4.00	1.20

Table 3 indicates that there were appreciable increments between the respondents' pre- and post-survey means for all TPACK sub-scales except for PK, where the teachers: STDT1A, STDT2A, and STDT2B, recorded a negative change (STDT1A=-0.29, STDT2A=-0.15, and STDT2B=-0.44) apart from STDT1B, who recorded a gain (0.43) on PK construct–suggesting that the student teachers did not expand their knowledge on instructional strategies to teach the subject matter even after the design and implementation of their SOPLs. The largest area of change between the student teachers' pre- and post-survey means differences as reported by STDT1A was for the sub-scale TPACK (0.80), followed by TPK (0.43), TK (0.40), and then TCK (0.33). For STDT1B, it was TCK (3.34), TPACK (2.80), TPK (2.44), and TK (2.42). For STDT2A and STDT2A, they were TPACK (1.60), TPK (1.29), TK (1.16), TCK (1.00) and TPACK (1.20), TCK (1.00), TPK (0.71), and TK (0.57), respectively. Thus, in all cases, constructs, which are technology-related seem to have recorded the largest changes. The least increment was reported in PCK for all the cases; but STDT1B reported the same increment for PCK and CK.

Various constructs of TPACK framework (especially the technology-related ones) were evident in the lesson plan documents that were developed as part of SOPLs, which suggested that student teachers' teaching had improved by use of PhET simulation. For example, the lesson plan documents, which were designed by design teams STDT1 and STDT2 for teaching the topics: *Deformation of solids* and *Frictional force*, respectively, showed evidence (see **Figure 2** and **Figure 3**) of how the student teachers developed their competencies for teaching high school physics in an improved manner.

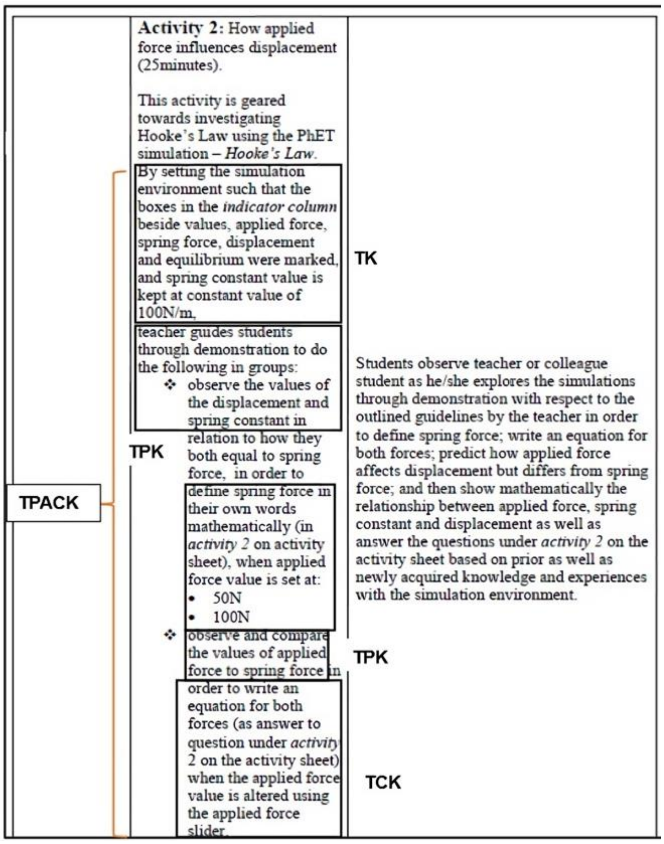


Figure 2. Extract from lesson plan document by STDT1 depicting their development of TPACK using HL PhET simulation environment (Source: Authors)

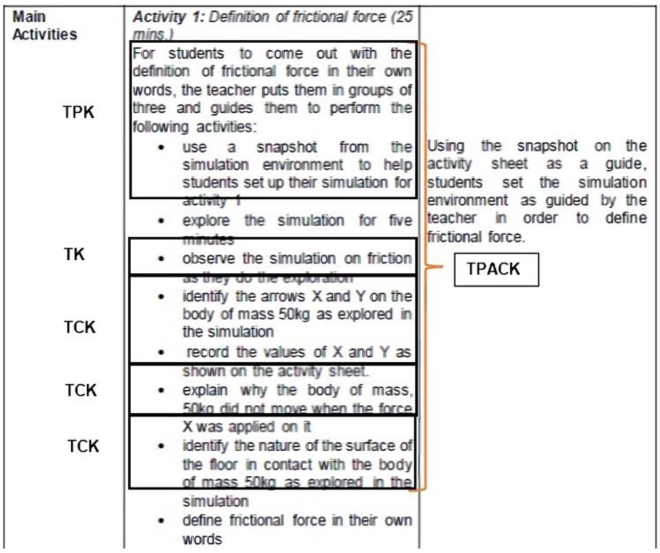


Figure 3. Extract from lesson plan document by STDT2 depicting development of TPACK using forces & motion: basics (friction) PhET simulation environment (Source: Authors)

Figure 2 for example illustrates how the student teachers' (in STDT1) developed TPACK, informed their teaching with the *Hooke's law* (HL) PhET simulation environment (see **Figure A1** in **Appendix** for simulation environment). Apparently, student teachers in STDT1 used their knowledge of the affordances of HL simulation environment (i.e., TK) to:

(1) guide learners through a demonstrative form of inquiry in achieving the activity's objective–"how applied force influences displacement" (i.e., making use of their TPACK),

(2) represent physics concepts associated with the topic, *Deformation of solids* in order to stimulate learners' observation and critical thinking abilities (i.e., making use of their TCK), and

(3) facilitate activity-based teaching (i.e., making use of their TPK).

Similarly, student teachers in STDT2 also made use of their developed TPACK in a way that shaped their teaching practices for the better as depicted in **Figure 3**. Elements of **Figure 3** were developed based on PhET simulation entitled: *Force and Motion: Basics (friction)* (see **Figure A2** in **Appendix** for simulation environment). It can be observed from **Figure 3** that the student teachers in STDT2 used their understanding of the interactive features of PhET simulation (i.e., making use of their TK) to:

(1) facilitate the teaching and learning process through an exploratory form of inquiry to achieve the learning goal set for activity 1: "definition of frictional force" (i.e., employing their TPACK),

(2) guide learners to explore and manipulate PhET simulation environment to specific settings that aligned with the tasks given in activity 1 (i.e., employing their TPK), and

(3) represent the concept of frictional force in a way that helps learners to define "frictional force in their own words" (i.e., employing their TCK).

The student teachers also reiterated during an interview with them after the design and implementation of their SOPLs during TITW that their teaching had improved because of their developed TPACK. Three of the student teachers indicated the following when asked about their teaching practices with the simulation:

> STDT2A: … I guided them with questions that directed them by exploring the simulation environment [TPK] … Even though they were using the simulation environment, the main purpose of the lesson was to use the simulations environment to answer the questions, which are based on the objectives of the lesson [TPACK].

> STDT1B: First, if I want to teach a topic, I will download the simulations that will best teach that topic [TCK], after that I will explore the simulation [TK] to see what I can use the simulation to teach in relation to that topic … [TPACK].

> STDT1A: As someone who was not actually having technology background [TK], to me with the help of this simulation, it is not necessarily about me learning how to use simulation to teach physics [TCK] particularly but using the simulations to direct me towards the various steps that I should observe in my teachings of physics [TPACK].

Student Teachers' Improved Content Knowledge

An alternative explanation for the observed improvements in teaching, facilitated by the integration of PhETs, could be attributed to the improvement in the student teachers' CK. Initially during TITW, some student teachers encountered challenges in articulating certain physics concepts. However, following the second implementation session, a discernible enhancement in their comprehension of these concepts was noted. Consequently, their ability to explain these concepts improved, subsequently improving their teaching when utilizing SOPL artefacts. This finding was corroborated by interview data. For instance, a student teacher identified as STDT2B expressed how his teaching evolved with the incorporation of PhETs. He exemplified this improvement by comparing his previous approach to teaching the concept of Friction in abstraction with his current ability to teach the same concept using PhETs. This transformation was attributed to his enhanced conceptual understanding of the subject, as revealed in the interview. He had the following to say during the interview when he was asked the question, "In what ways have your teaching of physics improved using PhET simulations?":

> When I chose the topic friction, I remembered that I had taught this topic [friction] before in SHS classroom, where I gave applications. Sometimes, the only thing I will say is that when we are walking, it is because of friction that we do not fall. In SHS classroom, students do not ask many questions when it comes to these applications, but then, when you are even preparing the lesson notes you go like "how am I going to teach this lesson?" … looking at the syllabus at that time, the syllabus did not demand much at that time. So, as a teacher, I had to try with all that I could to in my capacity to help them understand the very small part that they needed–sometimes, being theoretical. But, if I am teaching the same topic today, I think there is going to be much improvement with the simulation because, now I understand the concept very well and when we say something is opposing motion, now I can at least demonstrate something using the simulation for them to see and then, give explanation too. I think the students will get much understanding than what I used to give …

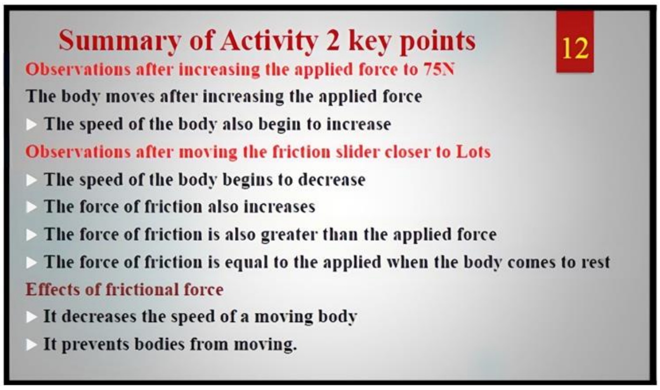


Figure 4. Summary of activity 2 as designed by STDT2 (Source: Authors)

The preceding comments seem to imply that the participant STDT2B lacked a comprehensive conceptual understanding of the concept of friction before engaging in the study. Consequently, he struggled to furnish concrete examples illustrating how the concept of friction could be applied in real-world scenarios during his prior teaching experiences. Apparently, this limitation hindered his ability to teach the topic effectively, leading to delivery of the instructional process in a somewhat abstract manner due to the absence of a thorough understanding. However, the incorporation of PhET simulations seems to have positively influenced his comprehension of the subject matter. This enhanced understanding enabled him to articulate the concept and its real-world applications more effectively. The presentation slides (**Figure 4**) created by design team STDT2 to summarize the activities designed for lesson on the topic: *Frictional force*, provided tangible evidence to support the assertion made in the interview.

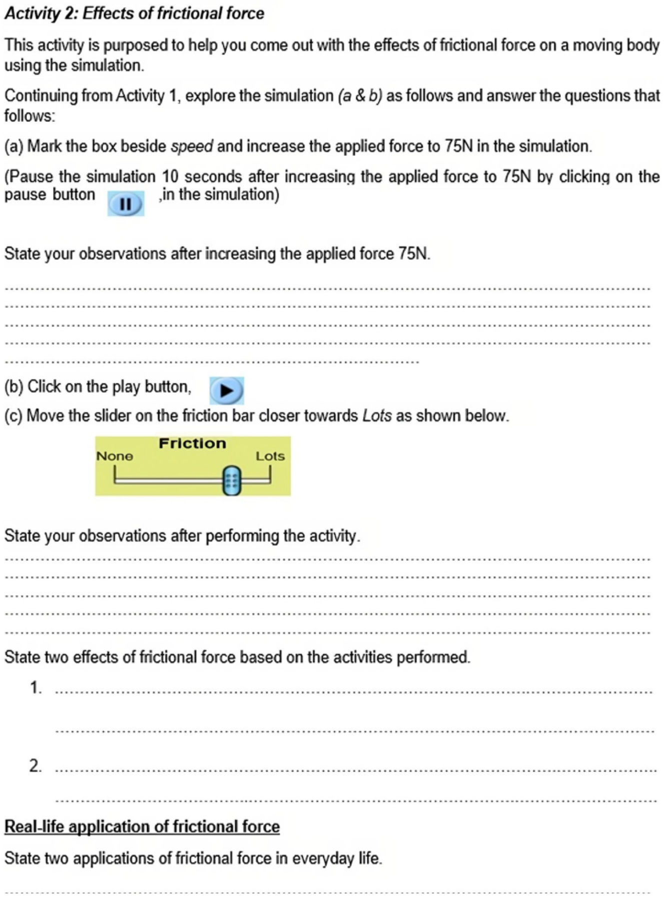
Figure 4 shows the explanations given by design team STDT2 in explaining the key concepts on the "effects of frictional force" to their learners in response to PhET simulation-oriented tasks they designed for activity 2 (see **Figure 5**) as part of their SOPL on the topic, *Frictional force*. This was a confirmation of STDT2B's statement that:

> "I think there is going to be much improvement with the simulation because, now I understand the concept very well and when, we say something is opposing motion".

It can also be inferred from **Figure 6** that not only was STDT2B able to explain the concept of *friction* better, but also, he was equipped based on his improved CK to guide his learners (course mate peers) in discussing common applications of *Frictional force* in relation to their daily lives' activities. This explains the improvements in his teaching observed during the delivery of his design team's lesson. The results here support that from the quantitative data for TPACK self-assessment survey (see **Table 3**), which reported a CK mean score of 3.60 for STDT2B before TITW and 4.40 after TITW–suggesting that STDT2B had improved his CK owing to PhET simulations.

Student Teachers' Developed Competencies in Exploring PhET Simulation Environments

Results from the qualitative data further revealed that the student teachers developed their knowledge and skills for exploring PhET simulation environments during TITW; as for most of them, the first



Activity 2: Effects of frictional force

This activity is purposed to help you come out with the effects of frictional force on a moving body using the simulation.

Continuing from Activity 1, explore the simulation *(a & b)* as follows and answer the questions that follows:

(a) Mark the box beside *speed* and increase the applied force to 75N in the simulation.

(Pause the simulation 10 seconds after increasing the applied force to 75N by clicking on the pause button ,in the simulation)

State your observations after increasing the applied force 75N.

....

(b) Click on the play button,

(c) Move the slider on the friction bar closer towards *Lots* as shown below.

State your observations after performing the activity.

....

State two effects of frictional force based on the activities performed.

1. ....

2. ....

Real-life application of frictional force

State two applications of frictional force in everyday life.

....

Figure 5. Activity 2 of STDT2's simulation-oriented physics lesson (Source: Authors)

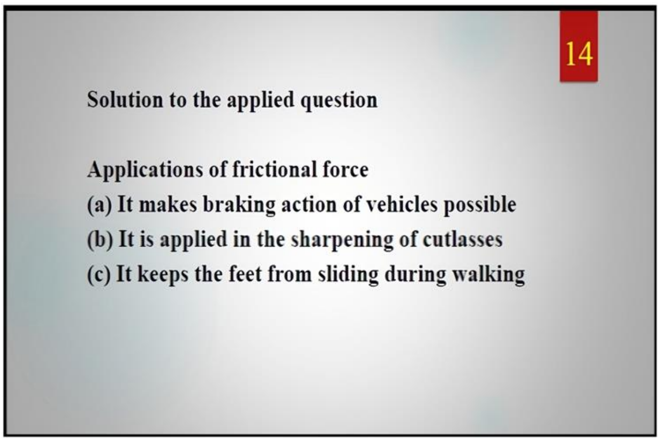


Figure 6. Summary of real-life application aspect of activity 2 designed by STDT2 (Source: Authors)

time they heard or encountered simulations was during TITW. Apparently, their consistent engagement with various PhET simulation environments and in-depth interaction with the content-driven interactive features of simulations during the design of PhET simulations-oriented lesson artefacts and their preparations prior to its implementation helped them to uncover the rich potentials of PhETs in representing various concepts in physics as well as direct their teaching of the subject matter in an interactive manner. These suggest that their teaching practices had improved owing to their developed competencies in the exploration of PhET simulation. This was confirmed by the student teachers during FGDs conducted after the implementation of their respective PhET simulations-oriented lessons.

In the post-teaching try-out FGD session, participants expressed unanimous sentiments regarding the effectiveness of PhETs as the medium through which they achieved enhanced teaching outcomes. They emphasized how the exploration of the simulation environment played a pivotal role in the observed improvements in their teaching practices facilitated by the training workshop.

> STDT1A: Without exploring the simulation, it is very difficult for the teacher to use it [simulations] in teaching. The reason being that we did not know how to teach or manipulate the various features of the simulations until we explored it many times.

> STDT1B: It is very difficult to teach with the simulation effectively without exploring before. Because effectiveness has to do with your competencies in exploring the simulation, but once you explore, you get to know more about it [simulation environment], understand it and translate what you understand to help get the concept right. So, I think it is good to always explore and prepare. Also, if you explore, you will know the method to go by in teaching the topic well.

> STDT2A: It is one thing having the content, and another thing to explore the simulation to know what the simulation features do. This is more like a practical session, where you can know what does what and where an apparatus must be moved to; it is just like having a device and not having its manual, you may end up misusing it. So, you need to explore the simulation and get to know where and what to do to find out the needed information you would require for teaching a particular topic. For example, you may see the features pictorially and you would want it to fit a particular topic but, without exploring, I found that you may get stuck on the way because, there might be some limitations to it [simulation environment], which will not get you there … so, it is best to first explore to know what it cannot and what it can before you go in to use it in the classroom …

> STDT2B: When you explore the simulation, you can teach faster and better for the students to understand because, during the class instruction, it is like working on something you have done before, it guides you to work within your set objectives …

The comments made by all four participants suggest that through their developed knowledge and skills in the exploration of PhET simulation environments, they gained deeper understanding into the affordances of PhET simulations, identified weaknesses in PhET simulations and in addition, became informed about the strategies to adopt to guide their learners to understand concepts in physics better. Hence, their teaching with simulations improved in a way that it became faster, easier, and activity-based with the focus on the learner.

It is important to mention that the competencies the student teachers gained in the exploration of PhETs as highlighted herein, seemed to have been driven by:

(1) certain components of TITW that were used as scaffold for grooming the student teachers into developing their

competencies in using technology(simulation) for the teaching of high school physics in an interactive manner and

(2) their sufficient CK especially, at the beginning of TITW.

In relation to the former, results from the interview data gathered from the participants of the study revealed that TITW components formed the basis for the improvements in teaching realized with student teachers, because of their developed competencies in the use and exploration of PhET simulations.

The following comments were the responses from three of student teachers of the study in response to the question, “In what manner did the training workshop impact your approach to teaching and exploration of PhET simulation?”:

> STDT1A: It exposed me to a lot of things … the workshop trained me to know a lot and guided us as a team to be able to know how best to incorporate simulations in physics instruction.

> STDT1B: I think I never knew about simulations until the workshop. So, it helped me by even making my work easier by exploring the simulation to be able to teach my content. It [referring to the initial workshop] exposed me to using a different approach to teach the same thing that I have taught before in a better and an easier way.

> STDT1B: … this workshop has helped us to use and explore the simulation or the technology effectively in our teaching. We realized through the exploration that we can involve, whereby the dimensions that we were taught in the workshop has to be in our teaching when using TPACK. So, we realized that … the group discussion or collaboration and those things were present, unlike our normal way of teaching, which is teacher centered.

All the comments made suggest that through TITW, the student teachers became knowledgeable about simulations and its use as a technological and instructional tool for TPACK driven teaching–an indication that TPACK model that the student teachers were exposed to during TITW, facilitated their developed TK.

In addition, FGD data revealed that the teamwork arrangement (i.e., the design team approach) employed during TITW helped the student teachers in developing their competencies in exploring the simulation environment to discover its potentials in ways that improved their teaching. The following were the comments the student teachers (belonging to design team STDT2) made in this regard:

> STDT2A: … working together helped us to share ideas on the simulation feature in making them either concrete or more understandable to us … When one person is exploring the simulation, you may think that what you are exploring is the right thing, but when there is another person there checking what you are doing, watching or helping out, the person can be able to pinpoint certain holes, with that, we come to an agreement that this approach would be the best.

> STDT2B: Working together, we got to know … as the saying goes “two heads are better than one”. In our case, as two different people, we came together to figure out something to be able to develop skills to explore the simulations and to understand it best.

STDT2B further explains using his experience with PhET (HL):

> Also, with HL, you will realize that the simulation has no manual so, for you to be able to explore it or use a particular simulation to teach a particular topic, you will really need to be guided, and there is no one to guide you. So, two heads coming together in a group will be that, when one person is exploring the simulation, the other person will be checking out to see whether what the other person is doing, matches the content; and so, it is like, we are trying to help each other to come up with the potentials in order to use the simulation to teach the content in a better way.

In relation to their sufficient CK, it was observed at the beginning of TITW that the student teachers, for example, STDT1A and STDT1B who constituted design team STDT1 had sufficient CK; this confirmed their perceived high CK (i.e., 4.00 and 4.00, respectively) before the training as observed with the results from self-report TPACK pre-survey data collected. Apparently, their sufficient CK facilitated their exploration of PhET simulations; they could easily appreciate the affordances of the simulation and thus, identify the topics from the Ghanaian physics curriculum for SHS as well as propose possible learning objectives that could be achieved informed by the interactive features of selected PhETs. They were also able to demonstrate how the proposed learning objectives they identified could be achieved by use of the simulation environments they selected. These observations were evident during the TITW whereby student teachers were tasked to

(1) explore a PhET simulation of choice under the high school physics section on PhET website,

(2) identify a topic from the GPC4SHS that could be taught with the selected PhET simulation,

(3) state one or two specific learning objectives pertaining to the selected topic based on the affordances of the selected simulation, and

(4) explain how the selected PhET simulation represented the objectives identified.

To achieve task 2 and task 3, the student teachers were expected to present their feedback pertaining to task 2 and task 3 on PowerPoint presentation slides for discussions. With task 4, they were required to demonstrate how features of their selected simulation environment could be used to achieve the objectives they enlisted.

In response to task 1, PhET simulation entitled: *Resistance in a wire*, **Figure 7** was chosen by design team STDT1.

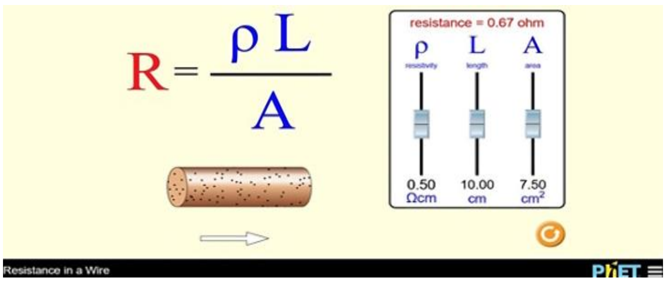


Figure 7. Unexplored interface of Resistance in a wire PhET simulation environment (https://phet.colorado.edu/)

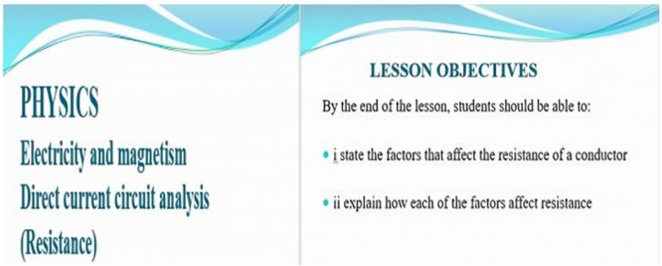


Figure 8. STDT1's responses to task 2 (left) & task 3 (right) (Source: Authors)

In response to task 2 and task 3, **Figure 8** shows evidence of the feedback given by STDT1 using PowerPoint presentation software.

From the GPC4SHS, the concept "resistance" is found in unit 1 (entitled: direct current circuit analysis) under section 5 (entitled: electricity and magnetism) for year two SHS science. This explains the information presented in **Figure 8** (left)–suggesting that the student teachers in STDT1 were specific in selecting a topic to be used with *RW* PhET simulation environment.

In addition, **Figure 8** confirms that the student teachers were able to discover the affordances of *RW* PhET and thus, were quick to identify the concept: "resistance" from the GPC4SHS as a probable topic to be taught with the *Resistance in a wire* simulation in achieving the learning objectives. When asked about what informed their choice of objectives (in response to task 4) as indicated in **Figure 8** (right), one of the student teachers belonging to STDT1 and identified as STDT1A explained as quoted:

> When we set the tab on the various elements [referring to the sliders associated with resistivity, ρ; length, L; and cross-sectional area, A, parameters in the RW simulation], then we decide to alter one parameter to see how it relates with the resistance or how it affects the resistance like the formula on the screen [he points to the formula in the simulation]. So, by altering each of these components, we see the effect that each one has on the resistance of the cylindrical conducting wire. So, that is what helped us to come up with the objectives.

The comment by STDT1A suggests that the student teachers had a clear understanding of the concepts that *RW* simulation and its interactive interface mimicked because of their seemly sufficient CK. Therefore, they were able to easily demonstrate how the concept, "resistance" was represented by *RW* simulation in relation to the length, L; cross-sectional area, A; and the material property (resistivity, ρ) of a cylindrical conducting wire. Results shown here affirm that sufficient CK on the part of the student teachers (before TITW) served as basis for their developed competencies in the exploration of PhET simulation environment.

The results presented so far provides substantive evidence that the student teachers improved in their teaching practices using PhET simulations because of their developed TPACK, improved CK and developed competencies in the exploration of PhET simulation environments. However, the road to realizing improvements in their teaching with technology was not without challenges:

1. Some of the student teachers encountered challenges in effectively exploring PhET simulation. A typical example was observed with the design team STDT2. The student teachers in this regard struggled in the exploration of the first simulation environment (entitled: *States of Matter*, denoted as *SM*, **Figure 9**) that they chose during a preliminary exercise conducted by the researchers at the beginning of TITW, prior to their actual design and implementation of the technology-oriented lessons. Their difficulty, apparently, was because of their insufficient CK. In the preliminary exercise, the student teachers (identified as STDT2A and STDT2B) were assigned the tasks of:

   (a) delineating potential learning objective from GPC4SHS that aligned with the affordances of *SM* PhET simulation environment and

   (b) elucidating how the simulation's affordances could be explored to fulfill the identified objectives in task (a).

   In response to task (a), they identified *SM* simulation's potential to differentiate between the three phases of matter (i.e., solid, liquid and gas). However, task (b) revealed their confusion regarding the specific feature of the simulation to be explored in order manifest the desired differences. Consequently, they attempted to interact with all the features within *SM* simulation environment but struggled to comprehend the implications of the simulation's responses to their explorations. The observed interaction indicated a lack conceptual understanding among the two student teachers regarding the various states of matter and their respective properties, impeding their ability to leverage prior knowledge in uncovering the affordances of *SM* simulation.

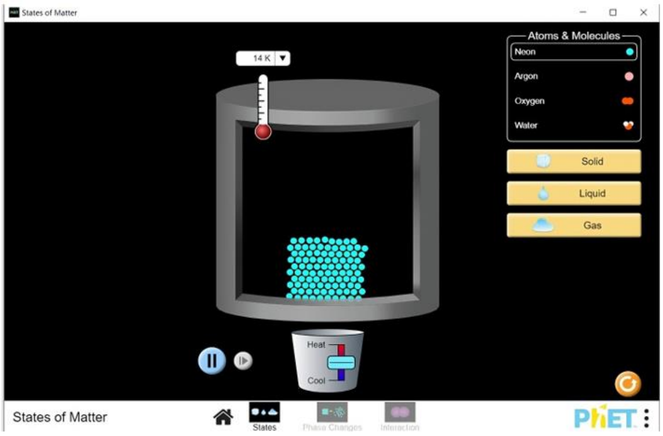


Figure 9. Unexplored interface of states of matter PhET simulation environment (https://phet.colorado.edu/)

2. All student teachers encountered challenges in establishing a relationship between and among the physics content, teaching strategies and the identified affordances derived from the selected simulation environment, which could subsequently inform the development of SOPL artefacts. This difficulty was corroborated through the interview conducted with some of the student teachers. In response to the question: "What challenges did you face during your preparations with PhET simulation while designing your lesson?" The participants articulated the following issues.

> STDT2B: … I had a little problem during the preparation because initially even when you introduced us to PhET simulation, I did not understand much about the simulation although you will see that they [referring to the developers of

> PhET simulations] have named the various simulations, but then, how to use it to teach was a challenge. So, that was the major problem I faced.
>
> STDT2A: … during the preparation, something that I had realized was that it demands creativity on the part of the teacher, you may have the content, you may have a very good simulation, but if you do not know how to use it or connect it into the content, you will have a problem. That was what made us struggle a lot in our group [referring to design team, STDT2]. Our main issue with the simulation had to do with how we could use it to develop our teaching and to guide the students to understand what we really wanted to teach or achieve the learning objectives.
>
> STDT1B: I think how to instruct them to use the simulations to solve the question on the activity sheet for me was difficult at the beginning.

Responses from the three student teachers seem to indicate not only a deficiency in their TPACK during the initial stages of the design process, but also a lack of proficiency in using PhETs to represent physics concepts (TCK) and employing simulations for activity-oriented teaching (TPK). It appears that their competencies in TK, necessary for exploring and understanding PhET simulations were also not well developed at the commencement of TITW for effective design of PhET simulations-based lesson artefacts. A possible reason for these challenges could be that they had not yet gained the knowledge and skills required for exploring and understanding the affordance of PhET simulations (TK) to incorporate its use in their teaching practices at the beginning of TITW. This aligns with findings from TPACK pre-survey, where the student teachers' self-reported mean scores for TK, TCK, TPK, and TPACK were notably low before initiating TITW, compared to that of their post survey scores for the same constructs. These scores suggest a perceived inadequacy in their competencies within these domains.

3. The design teams encountered a notable challenge in transitioning from a traditional teaching approach to a learner-centered approach in the context of physics instruction. This challenge became apparent through observations made by the researchers during the initial lessons that the student teachers designed at the onset of TITW. The observed instructional practices revealed that almost all student teachers utilized simulations in a predominantly traditional manner. In this approach, they assumed a central role in the instructional process, imparting knowledge of physics concepts rather than fostering an environment for students to construct their own knowledge based on the interactions with the simulation. Intriguingly, the teacher activities outlined for these preliminary lessons, conceived prior to the design of their respective actual SOPLs, suggested a learner-centered approach. However, during the actual delivery of these lessons, a teacher-centered approach was predominantly adopted.

DISCUSSION

The present study aimed to trace and gain understanding into the knowledge construction process of four physics student teachers as they develop and integrate technology-oriented lessons within the framework of a technology-integrated training workshop. Findings derived from the synthesis from quantitative and qualitative evidence revealed an improvement in teaching with technology. This was attributed the heightened TPACK, enhanced CK and improved competencies in exploring PhET simulations–manifested as developed TK among student teachers. These characteristics of the student teachers appear to constitute the key ingredients for enabling a shift from the teacher-centered teaching method to a learner-centered teaching method (Voogt, 2003) in the physics classroom, particularly where technology is involved.

Consequently, it is suggested that the acquisition of such technological competence may contribute to the advancement of their teaching practices. In the subsequent paragraphs we begin to discuss and explain the realization of the advocated paradigm shift based on the empirical findings of the present study.

The development of TPACK by the student teachers appears to facilitate a shift in paradigm. This is observed in the way the design teams practically integrated their TK, PK, and CK to reflect a transformative and integrative approach to TPACK (Chai et al., 2010; Harris et al., 2009), emphasizing the importance of combining these knowledge bases for effective teaching. The difficulty identified particularly at the initial stages of incorporating PhET simulations into lessons could be attributed to their limited familiarity with the technology and perhaps, need for a deeper understanding of how TPACK could be applied in the Ghanaian physics classroom context. This is consistent with Hutchison and Reinking's (2011) observation that when teachers lack the required technology-oriented knowledge, they seem to have difficulties in building on their existing PCK.

Another challenge observed in the process of development of the student teachers' TPACK was perhaps the difficulty they encountered in shifting from the traditional approach of teaching to a learner-centered way of teaching physics. This seems to suggest that the student teachers were entrenched in teacher-centric strategies at the beginning of TITW (Agyei, 2012). However, the study suggests that TPACK developmental process as entrenched in the TITW facilitated a shift towards a more learner-centered and technology-oriented pedagogies. This shift was reflected in decreased PK scores among the student teachers as observed from **Table 3**–indicating a transformation in the perception of pedagogy from teacher-centered to a more constructive and technology-integrated approach by the end of TITW.

The integration of PhET simulations into teaching was found to have enhanced CK of student teachers, leading to positive transformations in their teaching paradigm. The qualitative evidence (FGDs, interview, and lesson artefacts) indicated a shift from teaching physics abstractly to a more grounded approach based on a better understanding of the subject matter. The student teachers enhanced conceptual understanding could be attributed to the affordances discovered in PhET simulation environment, emphasizing the role of simulations in promoting content development. This finding aligns with Bell and Smetana's (2008) research, which highlights the importance of technology, specifically simulations, in enhancing CK in science classrooms.

Apparently, PhET simulations served as a platform for the student teachers, addressing gaps in their knowledge and improving their teaching practices. The study supports Wieman et al.'s (2010) assertion that simulations have the potential to enhance the efforts of the teacher, as reflected in the student teachers' improved ability to explain abstract physics concepts. The results in this regard suggest that PhETs contributed to a tangible improvement in the student teachers' CK, allowing them to better convey complex physics concepts. This underscores the effectiveness of incorporating PhET simulations into teaching practices for enhancing both the understanding, and consequently, the quality of instruction (Donnelly et al., 2011).

Improvement in teaching with PhET simulations is also attributed to the developed competencies of the student teachers in exploring the simulation environments. Apparently, the paradigm shift, revealed through interviews and FGDs, resulted from three key strategies: consistent engagement with diverse PhET simulations environments, in-depth interaction with content-driven features, and comprehensive preparations before implementing PhET lessons. These strategies seem to have enhanced the student teachers' TK, aligning with Webb and Cox's (2004) proposition that the use of technology in the classroom has significant implications for teachers. Apparently, the student teachers' efforts in adopting these strategies served as a crucial learning medium, enabling effective use of PhETs in teaching physics. Through these strategies, the results showed that the student teachers identified weaknesses in various PhETs environments, gained deeper understanding of affordances, and identified appropriate instructional approaches for conceptual understanding. Perhaps, the adoption of these strategies successfully created an activity-based learning environment using simulations as a technological tool. Furthermore, the student teachers' role in the classroom appeared evolved as they developed competencies in exploring PhET simulation–suggesting that the three strategies as incorporated in TITW, shaped their teaching practices, shifting the focus from teacher-centric control to a learner-centered, creative approach (Majumdar, 1997). The observed paradigm shifts, as discussed herein, among student teachers in their competencies with PhET simulations partially explain the observed improvement in their teaching practices. Although the development of competencies in the exploration of PhETs seems to have facilitated a shift in paradigm with respect to their teaching practices, the results revealed that some student teachers in the study initially encountered difficulties in exploring their first PhET simulation environment due to insufficient CK. As a result, they seem to have struggled to engage their prior knowledge of the subject matter to discover the affordances of the simulation environment they were tasked to explore prior during TITW. This suggests that the student teachers might have initially overrated themselves as having sufficient CK as observed in **Table 3**, when their CK was actually insufficient. Thus, the finding emphasizes that their lack of sufficient CK at the beginning of TITW was a hindrance to their discovery of the affordances of PhETs simulations. This provides support to the assertion that content is a necessary ingredient for effective teaching with technology (Mishra & Koehler, 2006).

Implications, Limitations, & Future Research

The implication of this study extends to various stakeholders in the field of science education. For teacher educators and policy makers, the findings emphasis the need to re-evaluate and enhance pre-service teacher education programs to incorporate theory-driven and content sensitive technology-mediated teaching and learning instructional processes. The study underscores the potential of TITWs informed by specific strategies and theoretical frameworks to equip pre-service teachers with the necessary competence for effective technology integration in science education.

While this research provides valuable insights into the professional development of student teachers for technology integration in science education, it is important to acknowledge certain limitations. The sample size of four student teachers may limit the generalizability of the findings, and future research could benefit from a larger and more diverse participant pool. Additionally, the study focused specifically on the teaching of high school physics, hence further investigations could explore the application of technology in other science subjects. Future works could also delve into longitudinal studies to assess the long-term impact of technology integration training on student teachers' instructional practice and student learning outcomes.

CONCLUSIONS

The present study, through a TITW informed by Tondeur's (2018) proposed strategies, tracked, and examined the progress of four student teachers in developing their competencies for integrating technology into the teaching high school physics using TPACK framework as a lens. With a goal to provide an explanation into how and why improvements in teaching using a technological tool such as simulations through implementation processes are possible, findings revealed that the student teachers improved in their teaching with simulations owing to their developed TPACK, improved CK, and developed competencies in the exploration of PhET simulations environment; suggesting a transformative shift in their teaching approaches, transitioning from a teacher-centered paradigm to a learner-centered one, particularly within the context of simulation environments. Despite initial challenges associated with insufficient CK, the establishment of relationships among physics content, teaching strategies and the identified affordances of the simulation environment as well as the shift from traditional to learner-centered approach, the study underscores the pivotal role played by the professional training arrangement adapted for the research.

Author contributions: EDA: conceptualizing research design, conducting literature reviews, collecting, & analyzing data, & contributing intellectual insights; **LCJ & TJ:** conceptualizing research design & contributing intellectual insights. All authors approved the final version of the article.

Funding: The authors received no financial support for the research and/or authorship of this article.

Ethics declaration: The authors declared that the study was approved by the institutional ethics committee of University of the Free State on 11 May 2017 (Approval code: UFS-HSD2017/0565). The authors further declared that participants were contacted for their voluntary participation in this study, after which, each participant was given in advance, an information sheet as well as a consent form to enable them to take a decision as to whether to participate in this study or not. Anonymity of participants was protected using pseudonyms.

Declaration of interest: The authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

REFERENCES

Agyei, D. D. (2012). *Preparation of pre-service teachers in Ghana to integrate information and communication technology in teaching mathematics* [Doctoral dissertation, University of Twente].

Agyei, D. D., & Voogt, J. (2012). Developing technological pedagogical content knowledge in pre-service mathematics teachers through collaborative design. *Australasian Journal of Educational Technology, 28*(4), 547-564. https://doi.org/10.14742/ajet.827

Agyei, D. D., & Voogt, J. (2014). Examining factors affecting beginning teachers' transfer of learning of ICT-enhanced learning activities in their teaching practice. *Australasian Journal Educational Technology, 30*(1), 92-105. https://doi.org/10.14742/ajet.499

Agyei, E. D., & Agyei, D. D. (2021a). Enhancing students' learning of physics concepts with simulation as an instructional ICT tool. *European Journal of Interactive Multimedia and Education*, 2(2), e02111. https://doi.org/10.30935/ejimed/11259

Agyei, E. D., & Agyei, D. D. (2021b). Promoting interactive teaching with ICT: Features of intervention for the realities in the Ghanaian physics senior high school Classroom. *International Journal of Interactive Mobile Technologies, 15*(19), 93-117. https://doi.org/10.3991/ijim.v15i19.22735

Akyeampong, K. (2003). *Teacher training in Ghana–Does it count?* DFID.

Angeli, C., & Valanides, N. (2009). Epistemological and methodological issues for the conceptualization, development, and assessment of ICT-TPCK: Advances in technological pedagogical content knowledge. *Computers & Education, 52*, 154-168. https://doi.org/10.1016/j.compedu.2008.07.006

Archambault, I. M., & Barnett, J. H. (2010). Revising technological pedagogical content knowledge: Exploring TPACK framework. *Computers & Education, 55*, 1656-1662. https://doi.org/10.1016/j.compedu.2010.07.009

Asare, B. K., & Nti, S. K. (2014). Teacher education in Ghana: A contemporary synopsis and matters arising. *SAGE Open, 4*(2). https://doi.org/10.1177/2158244014529781

Bell, R. L., & Smetana, L. K. (2008). Using computer simulations to enhance science teaching and learning. *National Science Teachers Association, 3*, 23-32. https://doi.org/10.1080/09500693.2011.605182

Buabeng, I., & Ntow, D. F. (2010). A comparison study of students' reasons/views for choosing/not choosing physics between undergraduate female non-physics and female physics students at University of Cape Coast. *International Journal of Research in Education, 2*(2), 44-53.

Buabeng, I., Ossei-Anto, T. A., & Ampiah, J. G. (2014). An investigation into physics teaching in senior high schools. *World Journal of Education, 4*(5), 40-50. https://doi.org/10.5430/wje.v4n5p40

Chai, C. S., Koh, J. H. L., & Tsai, C.-C. (2010). Facilitating pre-service teachers' development of technological, pedagogical, and content knowledge (TPACK). *Educational Technology and Society, 13*, 63-73.

Chai, C.-S., Koh, J. H. L., & Tsai, C.-C. (2013). A review of technological pedagogical content knowledge. *Educational Technology & Society, 16*(2), 31-51.

Darko Agyei, E., Jita, T., & Jita, L. C. (2019). Examining the effectiveness of simulation-based lessons in improving the teaching of high school physics: Ghanaian pre-service teachers' experiences. *Journal of Baltic Science Education, 18*, 21-42.

DeVellis, R. F. (1991). *Scale development: Theory and applications.* SAGE.

Donnelly, D., McGarr, O., & O'Reilly, J. (2011). Framework for teachers' integration of ICT into their classroom practice. *Computers & Education, 57*, 1469-1483. https://doi.org/10.1016/j.compedu.2011.02.014

Finkelstein, N., Adams, W., Keller, C., Perkins, K., Wieman, C. & the Physics Education Technology Project Team. (2006). High-tech tools for teaching physics: The Physics Education Technology Project. *Journal of Online Learning and Teaching, 2*(3), 110-121. http://jolt.merlot.org/vol2no3/finkelstein.pdf

Fisser, P., Voogt, J., Tondeur, J., & van Braak, J. (2015). Measuring and assessing TPACK (technological, pedagogical, and content knowledge), In J. Spector (Ed.), *The SAGE encyclopedia of educational technology* (pp. 490-493). SAGE.

George, K. (2014). *TPACK as a learning theory, education theory and practice.* University of Alabama.

Gess-Newsome, J. (1999). Pedagogical content knowledge an introduction and orientation. In J. Gess-Newsome, & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 3-20). Kluwer Academic Publishers. https://doi.org/10.1007/0-306-47217-1_1

Goktas, Y., Yildirim, Z., & Yildirim, S. (2008). A review of ICT related courses in pre-service teacher education programs. *Asia Pacific Education Review, 9*(2), 168-179. https://doi.org/10.1007/BF03026497

Harris, J., Mishra, P., & Koehler, M. (2009). Teachers' technological pedagogical content knowledge and learning activity types: Curriculum-based technology integration reframed. *Journal of Research on Technology in Education, 41*(4), 393-416. https://doi.org/10.1080/15391523.2009.10782536

Hutchison, A., & Reinking, D. (2011). Teachers' perceptions of integrating information and communication technologies into literacy instruction: A national survey in the United States. *Reading Research Quarterly, 46*(4), 312-333. https://doi.org/10.1002/RRQ.002

Kafyulilo, A., Fisser, P., Pieters, J., & Voogt, J. (2015). ICT use in science and mathematics teacher education in Tanzan: Developing technological pedagogical content knowledge. *Australasian Journal of Educational Technology, 31*(4), 381-399. https://doi.org/10.14742/ajet.1240

Kelly, M. A. (2008). Incorporating context into TPCK-based instructional design. In K. McFerrin, R. Weber, R. Carlsen, & D. Willis (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference* (pp. 5257-5262). AACE.

Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content (TPACK)? *Journal of Education, 193*(3), 13-19. https://doi.org/10.1177/002205741319300303

Koehler, M. J., Shin, T. S., & Mishra, P. (2012). How do we measure TPACK? Let me count the ways. In R. N. Ronau, C. R. Rakes, & M. L. Niess (Eds.), *Educational technology, teacher knowledge, and classroom impact: A research handbook on frameworks and approaches.* IGI Global. https://doi.org/10.4018/978-1-60960-750-0.ch002

Lawless, K. A., & Pellegrino, J. W. (2007). Professional development in integrating technology into teaching and learning: Knowns, unknowns, and ways to pursue better questions and answers. *Review of Educational Research, 77*(4), 575-614. https://doi.org/10.3102/0034654307309921

Lewin, K. M., & Stuart, J. S. (2003). *The MUSTER synthesis report: Researching teacher education: New perspectives on practice*. CIE.

Lim, C. P., Chai, C. S., & Churchill, D. (2011). A framework for developing pre-service teachers competencies in using technologies to enhance teaching and learning. *Educational Media International, 48*(2), 69-83. https://doi.org/10.1080/09523987.2011.576512

Majumdar, S. (1997). *Network based flexible learning: Prospects and challenges in the 21st century* [Invited talk]. The International Conference of Vocational Education and Training.

Miles, M., & Huberman, M. (1994). *Qualitative data analysis*. SAGE.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017-1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Mouza, C., Nandakumar, R., Yilmaz O. S., & Karchmer-Klein, R. (2017). A longitudinal examination of pre-service teachers' technological pedagogical content knowledge in the context of undergraduate teacher education. *Action in Teacher Education, 39*(2), 153-171. https://doi.org/10.1080/01626620.2016.1248301

Ottevanger, W., van den Akker, J. J., H., & de Feiter, L. 2007. *Developing science, mathematics and ICT education in sub-Saharan Africa (SMICT): Patterns and promising practices*. World Bank. https://doi.org/10.1596/978-0-8213-7070-4

Prabawa, H. W. (2017). A Review of gamification in technological pedagogical content knowledge. *Journal of Physics: Conference Series, 812*, 012019. https://doi.org/10.1088/1742-6596/812/1/012019

Price, A., Wieman, C., & Perkins, K. (2019). Teaching with simulations. *The Science Teacher, 86*(7), 6-52. https://doi.org/10.2505/4/tst19_086_07_46

Redish, E. F. (2003). *Teaching physics with the physics suite*. John Wiley & Sons, Inc.

Rosenberg, J. M., & Koehler, M. J. (2014). Context and technological pedagogical content knowledge: A content analysis. In M. Searson, & M. Ochoa (Eds.), *Proceedings of Society for Information Technology & Teacher Education International Conference* (pp. 2626-2631). AACE.

Sang, G., Valcke, M., van Braak, J., & Tondeur, J. (2017). Student teachers' thinking processes and ICT integration: Predictors of prospective teaching behaviors with educational technology. *Computers & Education, 54*(1), 103-112. https://doi.org/10.1016/j.compedu.2009.07.010

Schmidt, D. A., Baran, E., Thompson, A. S., Mishra, P., Koehler, M. J., & Shin, T. S. (2009a). Technology pedagogical content knowledge (TPACK): The development and validation of an assessment instrument for pre-service teachers. *Journal of Research on Technology in Education, 42*(2), 123-149. https://doi.org/10.1080/15391523.2009.10782544

Schmidt, D. A., Seymour, J., Baran, E. & Thompson, A. S. (2009b). *Developing effective technological pedagogical and content knowledge (TPACK) in prek-6 teachers* [Paper presentation]. The Society for International Technology and Teacher Education International Conference.

Shinas, V. H., Yilmaz-Ozden, S., Mouza, C., Karchmer-Klein, R., & Glutting, J. J. (2013). Examining domains of technological pedagogical content knowledge using factor analysis. *Journal of Research on Technology in Education, 45*(4), 339-360. https://doi.org/10.1080/15391523.2013.10782609

Tondeur, J. (2018). Enhancing future teachers' competencies for technology integration in education: Turning theory into practice. *International Journal of Media, Technology and Lifelong Learning, 14*(2), 216-224. https://doi.org/10.7577/seminar.2981

Tondeur, J., Aesaert, K., Prestridge, S., & Consuegra, E. (2018). A multilevel analysis what matters in the training of pre-service teacher's ICT competencies. *Computers & Education, 122*, 32-42. https://doi.org/10.1016/j.compedu.2018.03.002

Voogt, J. (2003). Consequences of ICT for aims, contents, processes, and environments of learning. In J. van den Akker, W. Kuiper, & U. Hameyer (Eds.), *Curriculum landscapes and trends* (pp. 217-236). Kluwer Academic Publishers. https://doi.org/10.1007/978-94-017-1205-7_13

Voogt, J., & Mckenney, S. (2016). TPACK in teacher education: Are we preparing to use technology for early literacy? *Journal of Technology, Pedagogy and Education, 26*(1), 69-83. https://doi.org/10.1080/1475939X.2016.1174730

Voogt, J., Pieters, J., & Handelzalts, A. (2016). Teacher collaboration in curriculum design teams: Effects, mechanisms, and conditions. *Educational Research and Evaluation, 22*(3-4), 121-140. https://doi.org/10.1080/13803611.2016.1247725

Webb, M., & Cox, M. (2004). A review of pedagogy related to information and communications technology. *Technology, Pedagogy and Education, 13*(3), 235-285. https://doi.org/10.1080/14759390400200183

Wieman, C. E., Adams, W. K., Loeblein, P., & Perkins, K. K. (2010). Teaching physics using PhET simulations. *The Physics Teacher, 48*(4), 225-227. https://doi.org/10.1119/1.3361987

Yawo, A. A. H. (2020). The influence of virtual physics laboratory on senior high school Form one physics students performance and cognitive achievement at Bishop Herman College, Kpando, Volta Region-Ghana. *International Journal of Engineering and Applied Science, 7*(9), 20-28. https://doi.org/10.31873/IJEAS.7.09.17

APPENDIX

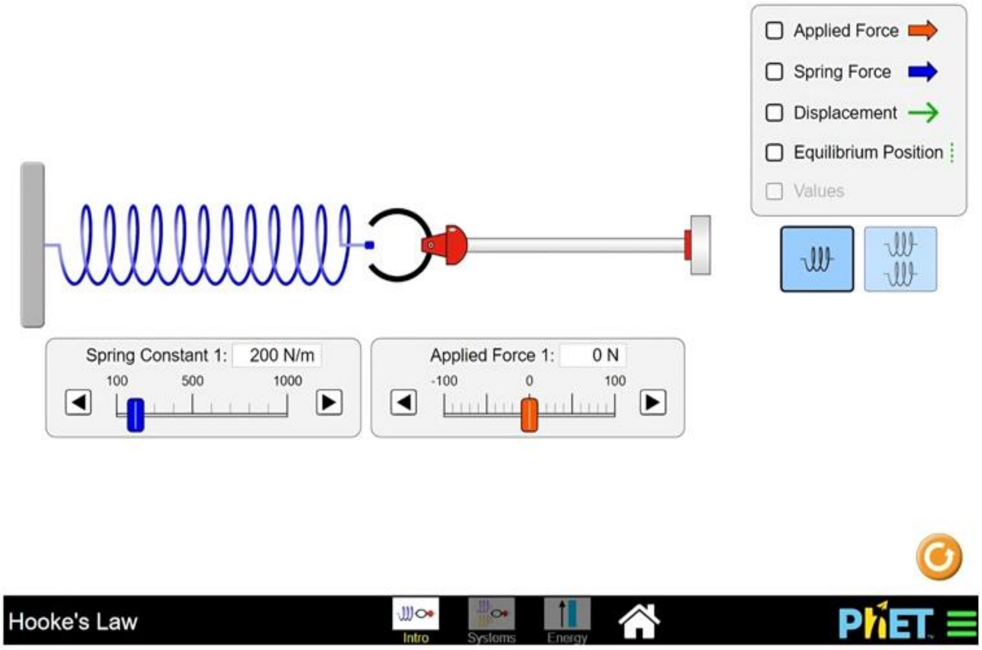


Figure A1. Snapshot of HL PhET simulation environment (https://phet.colorado.edu/)

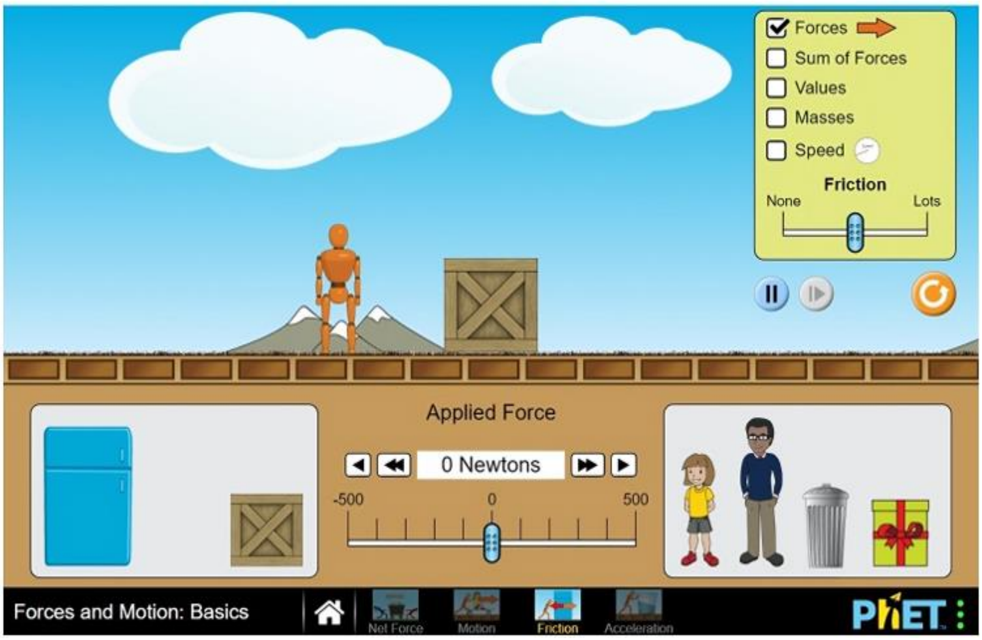


Figure A2. Snapshot of forces & motion: basics (friction) PhET simulation environment (https://phet.colorado.edu/)

Personal information

1. Name: ____________________
2. Teacher design team designation: ____________________
3. Topic taught: ____________________

Lesson planning and preparation

4. What encouraged you to select this topic or concept for integration of simulations?
5. What informed their choice of objectives with the simulations?
6. Have you taught the lesson before (during your off-campus teaching practice)? If you have, how did the incorporation of simulations affect your preparation for the lesson. (Did you prepare differently?)
7. How did the technology integration training workshop influence your preparation to teach this content with simulations?
8. What challenges did you face during your preparations with the PhET simulation while designing your lesson?

In-lesson activities

9. How will you describe the lesson activities? Convergent or divergent: learner-centred or teacher-centred? Please explain.

Post-review of teaching

10. How would you describe the teaching/instructional practices you adopted in teaching your selected topic with the PhET simulation?
11. Was the integration of the PhET simulations effective in achieving enhanced teaching outcomes?
12. In what ways have your teaching of physics improved using the PhET simulations?
13. In what manner did the training workshop impact your approach to teaching and exploration of the PhET simulation?
14. After teaching this lesson, what preparation do you think you need to do for another lesson that integrates simulations as tools for interactive teaching and learning?
15. Will you teach other physics concepts using simulations? If so, which concept? If not so why not?
16. Do you think that more technology-oriented professional development programmes are needed to improve your teaching of physics with simulations?
17. What general comment can you make about using PhET simulations in the SHS physics class?

Figure A3. Semi-structured interview guide (Adapted from Agyei, 2012)