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EXAMINING THE EFFECTIVENESS OF SIMULATION-BASED LESSONS IN IMPROVING THE TEACHING OF HIGH SCHOOL PHYSICS: GHANAIAN PRE-SERVICE TEACHERS' EXPERIENCES

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Abstract. *Teacher-dominated approach is still the most adopted teaching strategy in Ghanaian high schools despite the Government of Ghana's initiatives to support technology-oriented, learner-centred and interactive teaching practices. This study examined the effectiveness of simulation-based lessons in improving the teaching of high school physics by adapting the five dimensions for meaningful learning with information and communication technology model by Howland, Jonassen and Marra (2012) as a theoretical lens. Using an explanatory case study design, eight pre-service physics teachers from the University of Cape Coast, Ghana were engaged to develop and design simulation-based physics lessons in design teams and enact these lessons among themselves in microteaching sessions. Results showed that the simulation-based lessons were effective in that the pre-service teachers' teaching practices improved to be learner-centred and interactive. The results also suggested that although a combination of all the dimensions of meaningful learning was key to the effectiveness observed with each of the simulation-based lessons, the Cooperative dimension was found to possess a unique potential for sustaining the other dimensions in order to facilitate improvements in the teaching of physics with simulations.*

Keywords: *high school physics, ICT, interactive teaching, pre-service teachers, simulation-based lessons.*

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Introduction

The use of technology in education has become an important issue in the arena of educational research due to its remarkable affordances in the classroom. Technology provides authentic and interactive platforms for learner-focused teaching and learning process. Literature (McFarlane & Sakellariou, 2002; Fu, 2013) highlight the potential of technology for supporting and enhancing teaching by facilitating access to the subject matter. In light of this, many developed as well as developing countries have taken steps to initiate information and communication technology (ICT)-oriented education policies to advocate and emphasise the importance of technology integration into curriculum documents at all school levels (Agyei & Voogt, 2012). The Education Reforms launched in June 2007 by the Government of Ghana, for example, champion the use of ICT for teaching all subjects (Ministry of Education [MOE], 2007). For this reason, the Government of Ghana has since made provision for the initiation and implementation of the ICT in Education programme, especially at the high school (Upper-Secondary School) level of education. This was based on the recommendations of the Ghana Information and Communication Technology for Accelerated Development Policy (Ghana ICT4AD Policy, 2003) document, and purposed to improve teaching by means of ICT. In addition, the ICT in Education programme was introduced to provide teachers with the needed teaching skills and competencies in the use of ICT for school and classroom work (MOE, 2008).

The Government of Ghana has put in place many initiatives to transform the current teaching practices to more learner-centred methods that involve the creation of a highly interactive teaching and learning environment. However, it appears that the traditional teacher-centred approach is still the most dominant teaching strategy adopted for teaching most of the science subjects at the high schools in Ghana (Buabeng & Ntow, 2010; MOE, 2010). Apparently, most teachers prefer to use the curriculum to engage in a purely "chalk and talk" approach in teaching the science content, whereby students play the role of passive observers (Agyei & Voogt, 2012, p. 548). Although the Ghanaian physics curriculum for the high school is designed purposely to

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promote learner-centred teaching approach for better learning outcomes, the opposite is practiced in the Ghanaian high school physics classroom. That notwithstanding, the main teaching approach being adopted in Ghana to educate prospective teachers to teach various subjects including the sciences at the high school level is identified as purely teacher-centred, "where trainees are largely regarded as 'empty vessels', with little knowledge or experience of teaching" (Lewin & Stuart, 2003, p. 171). This seems to be the basis for the non-interactive and teacher-centred teaching methods being adopted for the teaching of physics at the high schools in Ghana.

The prospect of utilising ICT for enabling improvement in the teaching of physics in Ghana seems encouraging. Simulations for example, are noted for the creation of authentic classroom platforms which position the teacher as a facilitator and stimulate learning to occur through student engagement with guidance from the teacher (Wieman, Adams, Loeblein, & Perkins, 2010). In science classrooms all over the world, computer simulations have been of interest to researchers for over 20 years, with findings described as highly positive (Bell & Smetana, 2008). According to literature, simulations are of immense relevance for the development of content knowledge (Bell & Smetana, 2008), development of process skills, and provision of tools that promote scientific inquiry (Dwyer & Lopez, 2001).

The benefits of computer simulations as indicated in the literature reflect the key elements of constructivism and advocate the type of teaching approach that is best described as a "purposeful-inquiry" (Hofstein & Lunetta, 2003), where learning ceases to be the sole responsibility of teachers, but rather purposed to be a highly student-oriented process. In Esquembre's (2002) view, simulations are the most explored category of instructional software used in physics education. Benefits of computer simulations in relation to physics teaching include promoting interactivity in the physics classroom and affording students the space to explore a wide range of topics in physics through its Multiple Representation feature (Podolefsky, Perkins, & Adams, 2010). These potentials seem to project simulations as useful and interactive resource for effective teaching of physics. The effectiveness of simulations when used for teaching and learning purposes is noted to be highly dependent on: the way and manner in which it is used in the classroom; the design features; support structures put in place; and the alignment of the simulation-based activities with the intended curriculum (Bell & Smetana, 2008). This suggests that teachers have crucial roles to play in this respect, as their means of integrating simulations into their teaching practices may vary and, consequently, go a long way to influence the anticipated learning outcomes. Inevitably, teaching strategies must be carefully chosen to support meaningful learning of science (physics to be specific) with simulations in order for its potentials as an ICT tool to be realised effectively. It is against this backdrop that this study examines the effectiveness of simulations use as an interactive ICT tool in improving the teaching of physics in the Ghanaian high school classroom context. Specifically, Physics Education Technology (PhET) simulations (Finkelstein, Adams, Keller, Perkins, & the PhET Project Team, 2006) were used as the ICT tool for teaching high school physics.

Theoretical Framework

Meaningful learning is described in different terms as a way of learning that makes learners acquire new knowledge or to understand new information or concepts based on what they already know and their personal experiences (Jonassen, Howland, Marra, & Crismond, 2008). By this description, meaningful learning could be said to echo the ideology of constructivism in that it promotes meaning-making on the part of learners. Literature (e.g., Jonassen et al., 2008; Howland et al., 2012) highlight five attributes of meaningful learning: Active, Constructive, Intentional, Authentic and Cooperative. Each of these attributes of meaningful learning were defined in Jonassen et al. (2008, p. 7) and elucidated as follows:

- Active is described to mean "manipulative and observant", whereby learners are engaged actively in an environment that allows them to manipulate objects and parameters. In addition, learners are privileged to observe the results of their manipulations accordingly. Furthermore, activity alone cannot ensure meaningful learning. There should be room for learners to "articulate what they have accomplished and reflect on their activity and observations"; in other words, learners should be guided to be "constructive". This seems to emphasise the relationship that exists between the Active and Constructive attributes of meaningful learning. The degree of dependency is, however, not emphasised by the researchers in order to appreciate how the Active attribute/dimension when operationalised influences the Constructive and vice versa. There may be a crucial need for the identification of elements that uniquely define the two dimensions explicitly.
- Intentional is defined as being "reflective and regulatory", with emphasis on achieving a cognitive goal. This seems to suggest that whatever activity students are engaged in for knowledge construction, it

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should be goal-oriented and should be able to inform the way they think, the decisions they take as well as the strategies they adopt for achieving the set learning goals.

- Authentic is articulated on the basis that "we live in a complex world" and that the context in which ideas are based is crucial for meaning-making. Meaningful learning is therefore, in their view, complex and contextualised; hence, authentic in nature. This emphasises the importance of helping students relate ideas to their real-world contexts.
- Cooperative, in their view, involves collaboration propelled by conversations— providing an atmosphere where learners could learn from each other in order to appreciate the different ways of seeing the world.

Jonassen and Strobel (2006, p. 3) further highlighted that these attributes of meaningful learning are "interrelated, interactive, and interdependent" – that is, they do not exist in isolation for meaningful learning to be achieved; rather, it is their synergetic (or systemic) effect that bears value for teaching and learning purposes. This seems to hint that teaching and learning artefacts when considered for meaningful learning with the aid of ICT should be designed to promote active, constructive, intentional, authentic and cooperative learning. In agreement to this, Howland et al. (2012) proposed the five dimensions for meaningful learning with ICT (5DML-ICT) model on the basis that technology is not left out of the meaningful-learning picture. In Howland et al.'s (2012) view, technology plays an important role in achieving each of the attributes of meaningful learning—positioning ICT as the vehicle by which meaningful learning is brought to bear in the classroom.

Irrespective of the seemingly positive impact that the 5DML-ICT model has on teaching and learning processes with ICT, Koh (2013, p. 887) pointed out a number of issues to be resolved in any attempt to operationalise each of the dimensions/attributes of meaningful learning where ICT is involved. These included the facts that:

1) being active does not necessarily imply being constructive and for that matter, there is a need to give attention to how ICT defines the Constructive dimension by involving active learning—reiterating Jonassen, Howland, Moore and Marra's (2003, p. 7) assertion that "activity is necessary but not sufficient for meaningful learning". The issue raised in this regard seems to suggest a possible relationship between the Active and Constructive dimensions of meaningful learning; however, it is not clear what kind of relationship exists between the two, as indicated earlier. Thus, the need to clearly expatiate on the extent to which the Active dimension informs the Constructive and vice versa.
2) there should be evidence of how lesson activities developed and designed by teachers are aimed at involving students in order to help them fill in their learning gaps with ICT and this should be peculiar to the Intentional dimension.
3) ICT lesson activities should be designed as a means for "personal meaning-making" (Koh, 2013, p. 889) in the Authentic dimension.
4) the use of divergent tasks, as indicated by Harris, Mishra and Koehler (2009), would best represent the prospects of the Cooperative dimension (Koh, 2013).

Koh's (2013) views perhaps provided insights into how teaching and learning materials should be designed with ICT to facilitate improvement in teaching through the creation of an interactive and learner-centred teaching and learning environment. This informed the 5DML-ICT application adapted in this study. Specifically, the study employed and adapted the 5DML-ICT model in line with issues raised by Koh (2013) as a framework for characterising and defining interactive teaching of physics with simulations. By considering the propositions made by Koh and informed by Koh's (2013, p. 893) "Rubric for assessing TPACK for meaningful learning with ICT", this study adapted a conceptual framework that considers how the idea of ICT as the vehicular tool in instruction informs the way a teacher teaches in an interactive manner. Interactive teaching was defined in the context of this study to mean: a teaching method that is learner-centred, with teachers creating various avenues and structures that are ICT-oriented in ways that stimulate learners to be active, constructive, authentic, intentional and cooperative in a constructivist teaching and learning environment. Consequently, the following operationalisations were made and used to measure the effectiveness (i.e., the extent to which the five dimensions were realised in the design and implementation of the SBPLs) of the simulation-based lessons designed:

- Active: The use of PhET simulation(s) in lesson activities to engage learners in learning the subject matter.
- Constructive: The use of PhET simulation(s) in lesson activities to stimulate students to reflect upon the subject matter and express their ideas and meaning beyond what is presented to them.

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- Authentic: The use of PhET simulation(s) in lesson activities to connect students' personal experiences to the real world.
- Intentional: The use of PhET simulation(s) in lesson activities to engage students in diagnosis, evaluation, and improvement of the learning gap.
- Cooperative: The use of PhET simulation(s) in lesson activities to engage students in groupwork for divergent knowledge expressions.

By these operationalisations, this study sought to address the question: "How effective are simulation-based lessons in improving the teaching of physics". Also, informed by these operationalisations, the five dimensions for meaningful learning were conceptualised as the "dimensions of interactivity" whereas the realisation of interactive teaching with ICT (simulations) was taken as evidence for improvement in teaching.

Research Methodology

General Background

The research used an explanatory case study design of eight pre-service teachers to gain an in-depth understanding into the extent to which the use of simulation as an interactive ICT tool improves the teaching of physics. Consequently, the main entity studied (i.e., units of analysis) were the pre-service teachers. The research employed both qualitative and quantitative methods of data collection and analysis. This was done to ensure triangulation of the data. It is important to mention that the quantitative evidence in this regard was not intended for making statistical generalisations, but rather for arriving at a holistic understanding of the phenomenon being considered (Yin, 2003). Data were collected over a stretch period of eleven weeks. However, within this time frame, data collection was subjected to the convenient times of the participants.

Participants

Eight pre-service physics teachers participated in the research. Four of them were in their final year of the science teacher education programme at the University of Cape Coast, with the remaining four in their third year of the same programme. In selecting the participants, purposive sampling was used, with characteristics such as accessibility, commitment, and seriousness as the criteria for selection, subjected to the researchers' experience and knowledge of the pre-service teacher participants (Kothari, 2004). The average age of the participants was nearly 28 years. The participants had not had any training before on the design and implementation of ICT-supported lessons. Thus, an initial training workshop was organised in order to equip them with content-focused as well as theory-induced ICT-oriented knowledge and skills needed for the effective design, development and implementation of an ICT (simulation)-supported lesson. Based on the knowledge and skills acquired through the initial training workshop, the participants worked in design teams (DTs) of two to design, develop, and implement the SBPLs (Table 1).

Table 1. Summary of simulation-based lessons developed and implemented by participants.

Design team (DT) designation	Participant pseudonyms	Designated name for SBPL	Topic taught	Lesson duration	Name of PhET environment used
DTA1	Kwesi Kwame	SBPL_1	Reflection and refraction of light	80 minutes	Bending Light
DTB1	Kwabena Esi	SBPL_2	Structure of the atom	80 minutes	Build an Atom
DTA2	Ansah Owusu	SBPL_3	Deformation of solids	80 minutes	Hooke's Law
DTB2	Darkwah Mofe	SBPL_4	Frictional force	80 minutes	Force and Motion: Basics (Friction)

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As shown in Table 1, four lessons were developed and implemented in the study. The table gives an overview of the lessons developed and implemented. These lessons were enacted in microteaching try-out sessions among the participants. Thus, the participants who were not teaching acted as learners while the other participant pairs were teaching.

Ethical Considerations

Participants were contacted for their voluntary participation in the study. In order not to coerce them into participating, the participants were given in advance an *Information Sheet* and a *Consent Form*. This was meant to provide them with adequate time to decide as to whether to participate in the study or not. The anonymity of the participants is protected by use of pseudonyms, as indicated in Table 1.

Instruments and Procedures

Both qualitative (i.e., focus group interviews [FGIs], direct observation, and lesson artefacts) and quantitative (questionnaire) data collection techniques were used. FGIs were used to collect data after each microteaching try-out session with each of the simulation-based lessons developed by the participants. Four focus group discussion sessions were planned and directed for the participants to reflect on: a) the appropriateness of the designed lessons for selected topics in physics and b) the extent to which the lessons promoted interactive teaching. Thus, sample questions of interest for the FGIs were: 1) *Were the interventions appropriate for the physics topics selected for the lesson*? and 2) *To what extent did the intervention promote interactivity during the lesson?* Direct observation method was also used for data collection, in which process one of the researcher's logbook was employed to keep vivid and detailed accounts of the activities and events that occurred during enactment of the simulation-based lessons. This also served as a strategy for ensuring credibility of the data gathered. In addition to FGIs and the direct observation, lesson artefacts for all four SBPLs developed by the participants were also used as sources of data. These comprised lesson plan documents, student activity sheets, and presentation slides, all designed based on a selected PhET simulation environment.

For the quantitative data collection, the Five-dimension Survey (5dS) questionnaire was used to measure the extent of interactivity considered by the participants (i.e., learners) in the design and implementation of the simulation-based lessons. Table 2 presents a sample item for each dimension.

Table 2. Sample items for each dimension from the 5dS questionnaire.

Dimensions of interactivity	Sample items
Active	I used almost all the lesson time to explore the simulation environment working with the subject matter.
Constructive	The simulation-supported lesson articulated my personal understanding of the physics topic taught.
Authentic	The simulations helped me to represent my personal experiences of the real-world phenomenon in relation to the subject matter.
Intentional	I self-diagnosed the learning gaps of the subject matter by using the simulations which helped me to fill in the gaps in my knowledge.
Cooperative	Group activities in the lesson with the simulation environment allowed me to reflect, discuss, and share ideas about the physics concept with other learners.

The 5dS questionnaire was designed to include items adapted from Koh's (2013, p. 893) "Rubric for assessing TPACK for meaningful learning with ICT". The questionnaire contained 29 items on a 5-point Likert scale (1 = strongly disagree; 5 = strongly agree), grouped under the Active (6 items), Constructive (6 items), Authentic (6 items), Intentional (4 items) and Cooperative (7 items) dimensions of meaningful learning (Howland et al., 2012; Koh, 2013). Koh (2013) reported that Cohen's kappa values above 0.80 indicate high reliability of a measuring

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instrument. Since all five dimensions in this study obtained values above that (i.e., Active: 0.93, Constructive: 0.93, Intentional: 0.89, Authentic: 0.85, Cooperative: 92), reliability was thus achieved. The questionnaire was administered after each simulation-based lesson had been enacted. An average of 3 and above indicates a positive favourable opinion, while below 3 indicates a negative opinion of the 5dS.

Data Analysis

The quantitative data were analysed by use of descriptive statistics (i.e., means and standard deviation), while the qualitative data (e.g., observation and FGIs) were analysed through data reduction (Miles & Huberman, 1994). This was accomplished by identifying themes as well as patterns in line with the adapted framework for the study. Document analysis was employed to analyse and give meaning to the word-based data gathered from the participants' SBPL artefacts, with keen interest in the designed lesson activities.

Research Results

Pre-service Teachers' Reported Activeness of the Developed Lessons

The qualitative evidence revealed that the participants used their selected simulation environment to engage their learners in learning the subject matter (i.e., Active). Table 3 shows evidence (from the FGIs) of the extent to which the participants perceived the Active dimension to have been realised in the design and implementation of each of the four SBPLs. Evidence was gathered from the FGIs that were conducted after each microteaching try-out session for SBPL_1, SBPL_2, SBPL_3 and SBPL_4. For each lesson, the evidence gathered was in response to the question: "*To what extent did the intervention promote interactivity during the lesson?*". Table 3 gives example of comments from participants (learners) from different focus groups.

Table 3. Participants' perceptions about the four SBPLs in relation to the Active dimension.

Focus group interview	Participant	Response
FGI for SBPL_1	Esi	In the course of the lesson, we were involved a lot, and we did almost everything … So, I realised it was very interactive.
FGI for SBPL_2	Kwabena	It was interactive in the sense that for some of the activities, we were using simulations, so we were active.
FGI for SBPL_3	Mofe	It was active because we gave them the opportunity to explore …
FGI for SBPL_4	Ansah	We had the opportunity to interact with the simulations.

Results from Table 3 show that the Active dimension was realised mainly by engaging learners to interact with the simulation environment themselves and/or to explore the manipulative features of the PhET simulation environment. Apparently, this was intended to help them learn the subject matter. Activities that were designed on the activity sheets by the participants (i.e., design teams) also confirmed this (see Figure 1). Figure 1 (i.e., a sample activity for SBPL_4) shows that the participants engaged their learners to explore the Forces and Motion: Basics (Friction) PhET simulation environment by manipulating its interactive features (e.g., *speed* check box, the *pause* button, *friction* slider etc.). This was purposed to facilitate their learning of the subject matter— "Effects of frictional force" (see underlined areas in Figure 1).

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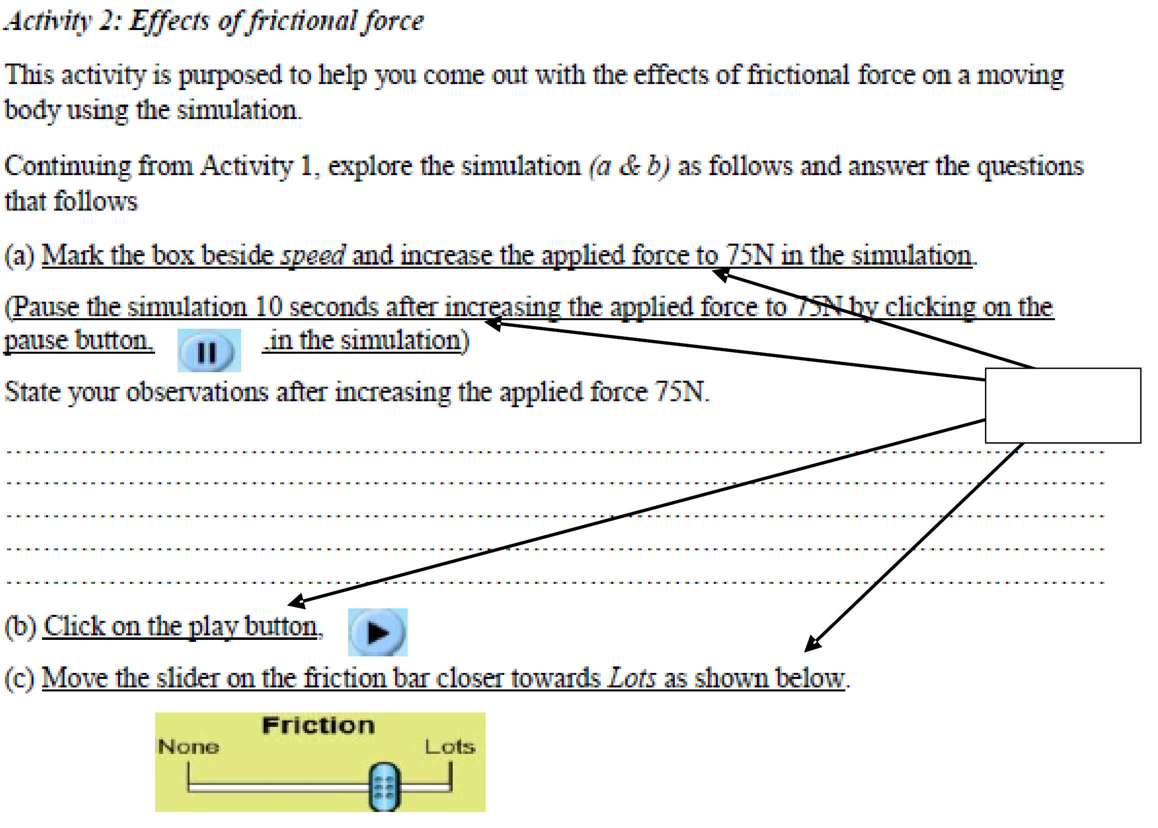

Activity 2: Effects of frictional force

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.

Figure 1. Sample activity for SBPL_4 in realising the Active dimension.

Pre-service Teachers' Demonstration of the Constructive Dimension with Lessons Developed

In determining the extent of the Constructive dimension of interactivity projected with the developed lessons, the results showed that the participants were able to use the PhET simulations to design lesson activities to encourage learners to reflect upon the subject matter and express their ideas and meaning beyond what was presented to them. In the FGIs conducted after the implementation of each of the four SBPLs, the participants echoed that the lessons were interactive in projecting the Constructive dimension (see Table 4). Table 4 shows some of the evidence gathered from the FGI data. Specifically, evidence was gathered in response to the question: "*To what extent did the simulation-based physics lesson promote interactivity during the lesson?*" As can be inferred from the sample comments presented in Table 4, the participants perceived the lessons to be interactive because they were able to form their own personal meaning of the subject matter.

Table 4. Participants' perceptions about the four SBPLs in relation to the Constructive dimension.

Focus group interview	Participant	Response
FGI for SBPL_1	Kwesi	We built our own knowledge in doing the activities.
FGI for SBPL_2	Kwame	We were able to build our own atom of a particular element for ourselves using the simulation.

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Focus group interview	Participant	Response
FGI for SBPL_3	Ansah	Yes, it was interactive because in my last presentation [lesson], there was a particular question on introductory activity which I was not expecting them to write, that the applied force equal to minus $kxkx$ [referring to the mathematical expression for Hooke's law], but one of them knew when he was observing the simulation that there should be a negative sign, so the students learned the concept beyond what I was expecting.
FGI for SBPL_4	Ansah	Based on the lesson, I understood the concept, especially when we say something is opposing motion.

The comments in Table 4 also seem to hint that it was the learners' engagement with the simulation environment in learning the concepts under study (indicated by the underlined statements in Table 4) that provoked them to express their ideas and make meaning beyond what had been presented to them. These results confirmed what was observed during the microteaching sessions for each intervention. Remarkable evidence of the Constructive dimension was witnessed during the microteaching try-out of SBPL_1 by DTA1 using the Bending Light (BL) PhET simulation. This had to do with the latter part of the lesson, where Kwesi, in his teaching, involved his learners in a whole class discussion on a real-life application problem given under Activity 2 of the SBPL_1 activity sheet (see Excerpt 1) after learners had worked on the activity as a group.

Real life application

1. A ray of light incident at an angle in air to the surface of water is reflected at an angle of 60°. Find the angle of refraction.

Excerpt 1. Real-life application question under Activity 2 of SBPL_1 activity sheet designed by the participants in DTA1.

Led by the 'teacher', the learner group was asked to share their solutions with their colleague learners (the other participants). In particular, the teacher asked the group leader to write his group's solution on the board and to explain how they came up with the solution they presented verbally (apparently, this was purposed to help the 'teacher' determine if they had constructed their own meaning of the concepts discussed in the course of the lesson). Interestingly, the group leader presented only the final answer to the question on the board, which was correct as it aligned with the final answer of the 'teacher'. When asked about their solution, the group leader explained that they had used the BL simulation environment to solve the problem. The group leader, with the support of his co-group members, further used the simulation environment to demonstrate how they had arrived at the final answer. Their responses, as observed, indicated that they did the following to arrive at the final answer:

- clicked on the refresh button in the BL simulation environment—by this action, the simulation interface changed to the fundamental state.
- adjusted the slider on the material tab for medium of refraction from "Water" to "Glass". This action, the group leader explained, was informed by a hint given by the 'teacher' in the real-life application question. Consequently, the colour for the medium of refraction in the simulation changed from sea blue to violet and the value for the index of refraction in the simulation increased from 1.33 to 1.50, indicating a change in the medium of propagation from water to glass.
- clicked on the red button on the light source to release the light ray. Upon incident on the Air-to-Glass interface in the simulation environment, it was partly reflected and partly refracted.
- moved the virtual protractor from its initial location and dragged it (by use of the computer mouse) until its centre fell exactly along the "Normal" line in the simulation environment.
- adjusted the light source handle down until the ray of light was at an angle of 60° away from the "Normal" line, with the help of the protractor.
- finally, measured the corresponding angle that the refracted ray made with the "Normal" line in the glass medium.

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With these steps, the result obtained by use of the BL simulation environment with respect to the real-life application problem was as shown in Figure 2—suggesting that at an incident angle of 60°, the angle of refraction is approximately 35°.

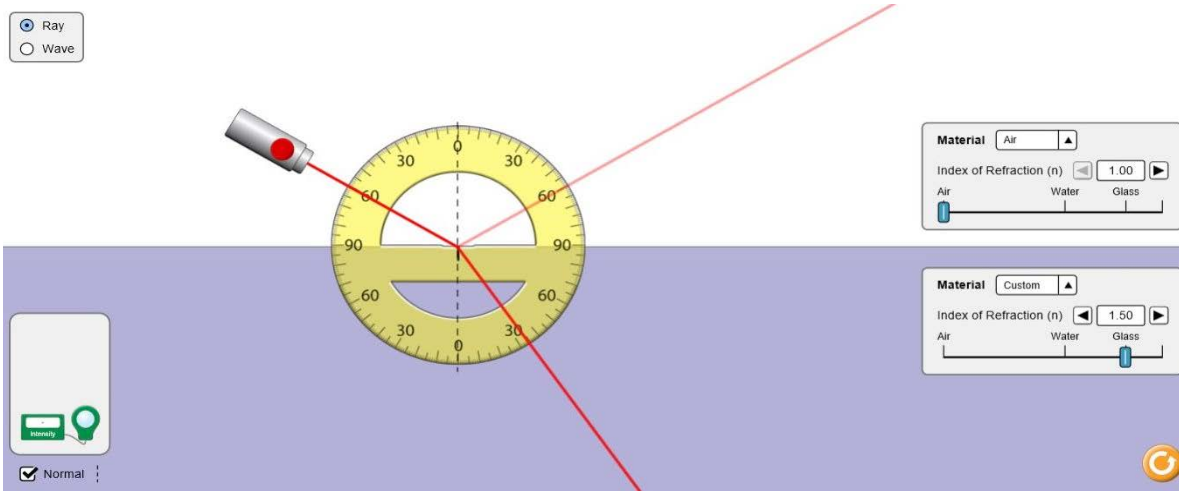
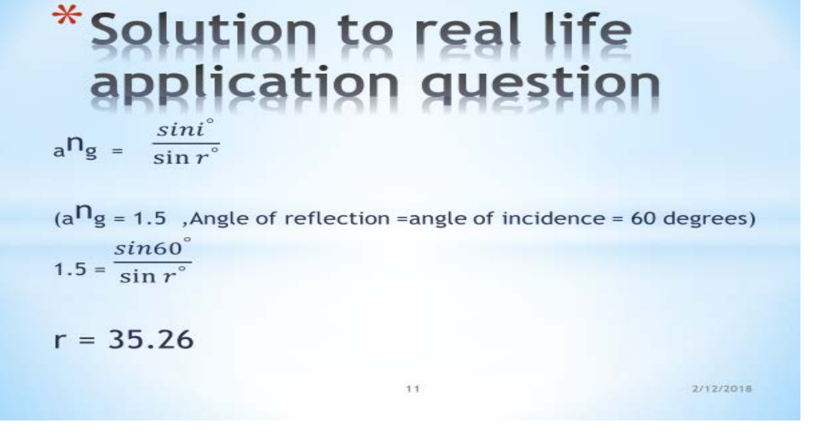


Figure 2. **Snapshot of the alternative solution presented by learners in relation to the real-life application problem using the Bending Light simulation.**

After these remarkable demonstrations and explanation given by the learner group, the 'teacher', Kwesi, seemed astonished at the group's approach to solving the application question. As was observed, Kwesi stood for over 30 seconds before making an utterance. He later hinted that he was perplexed because during the design of the lesson, he and his team member (i.e., Kwame) had never considered using the simulation environment to solve the real-life application problem. The following were Kwesi's words:

> I solved the real-life application question; I solved it in a mathematical way. I had to calculate, and I was expecting them to do likewise. I never thought of using the simulation. But then, I was surprised when a group of students just simply used the simulation, measured and they had the answer straightaway. I was very surprised, it was unexpected…; it was a very good attempt on their part.

Apparently, Kwesi and Kwame (in DTA1) incorporated the real-life application problem thinking of a mathematical approach to solving the problem. This was evident in the solution they provided on a slide (as shown in Excerpt 2) in relation to the real-life application question under Activity 2 in the course of the lesson.



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Excerpt 2. Slide presented to learners by Kwesi as the solution to the real-life application problem.

As seen in Excerpt 2, Kwesi (together with Kwame) solved the problem by employing the mathematical expression for Snell's law of refraction, and then substituting the parameters given in the question as well as that provided by the simulation environment (that is, the angle of incidence [= 60°; denoted ii] and refractive index for glass [= 1.5; denoted $_{1}n_{g}$], respectively) into the mathematical expression to arrive at the answer ($r = 35.26$ $r = 35.26$; where rr denotes the angle of refraction in degrees). Results from the lesson suggest that the learner group, in reflecting on the subject matter to express their ideas and meaning of Snell's law, went beyond that which was presented to them in the course of the lesson to answer the real-life application question. Based on the observations made, they seemed to have been actively engaged throughout in their quest of providing a solution to the real-life application question on the activity sheet. This was a clear indication that the intervention with the BL simulation was effective in realising the Constructive dimension and, consequently, seems to suggest that the participants, in their design of the activities to engage their learners actively, created an avenue for knowledge construction. This supports the results from the FGI data (i.e., Table 4), which suggested that the Active dimension was essential in realising the Constructive dimension.

Pre-service Teachers' Demonstration of the Authentic Dimension with Lessons

The SBPLs of the participants were also designed to connect students' personal experiences to the real world (i.e., *Authentic*) and hence, were effective in improving the teaching of physics. The FGI data as indicated in Table 5 support these results. The main question of interest during each of the FGIs was: "*To what extent did the intervention promote interactivity during the lesson?*" This was followed up with questions like: "*What can you say about the whole lesson with the simulations?*" and "*Was the simulation's use in the lesson effective?*" The responses presented in Table 5 were all selected based on their projection of the Authentic dimension of interactivity.

Table 5. Participants' perceptions about the four SBPLs in relation to the Authentic dimension.

Focus group interview	Participant	Response
FGI for SBPL_1	Esi	It was authentic because it was based on what or how "reflection" really happens in the real world.
	Kwame	I think this takes us from the very abstract context of teaching and learning physics. Normally, before the simulations, we are told or the teacher just sketch on the board, so we don't see movement and we don't get to see what is really happening about the laws of reflection; we are just told: "… angle of incidence is equals angle of reflection"; but with this lesson, we did it, measured it, so we are involved, and we realised that what has been said or what is being said about the law is really what is happening using the simulation. So, we moved from the abstract context of teaching and learning to the real or the hypothetical real world of teaching and learning.
FGI for SBPL_2	Kwesi	It was authentic because we solved real-world issues where we built our own element using the protons and other subatomic particles in the simulation.
FGI for SBPL_3	Mofe	It took us from the abstract way of learning the concept to a real-life experience kind of thing.
FGI for SBPL_4	Ansah	For me, I used to see the concept of friction as something weird and something abstract. But with this lesson, we are able to see what friction is about.
	Darkwah	Everybody wants to be associated with a concrete method of teaching. So, once we are able to verify the activities that the teacher was talking about practically, it is authentic.

The results in Table 5 suggest that the participants perceived the PhET simulations to be interactive because the simulations provided a platform for them to link their personal experiences in learning the subject matter to the real world. Apparently, this enabled a shift from learning physics concepts in abstraction to verifying physics concepts practically; they got to see concepts being represented virtually, which encouraged them to appreciate how the physics concepts were applied in the real world.

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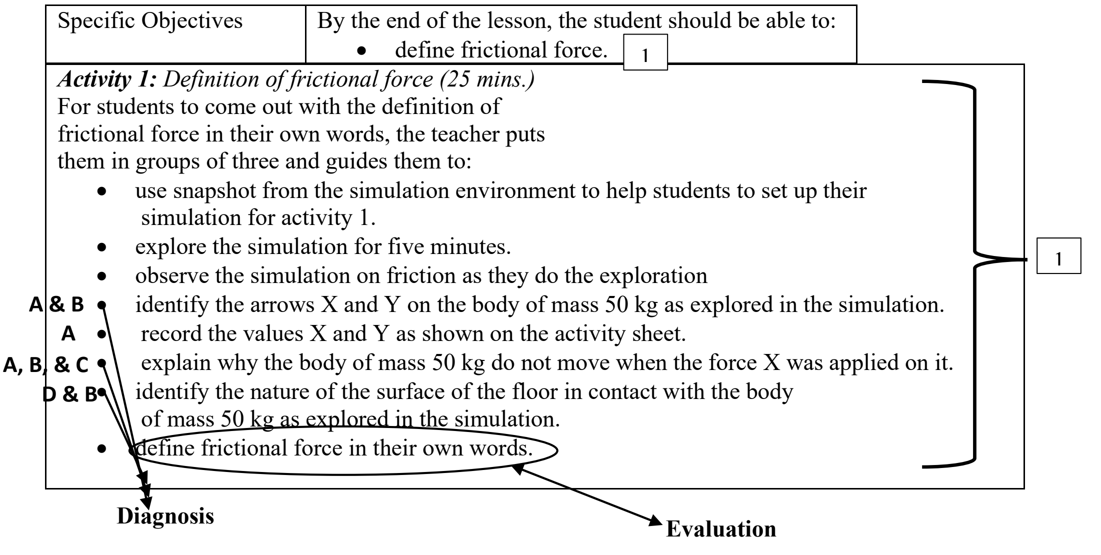
Pre-service Teachers' Demonstration of the Intentional Dimension with Lessons

Results of the study also indicated that the participants used the PhET simulations in the design of their respective lesson activities to engage learners in diagnosis, evaluation, and improvement of the learning gap; this was an indication of the extent to which the Intentional dimension was realised (Figure 3). Each of the elements (i.e., diagnosis, evaluation, and improvement of the learning gap) of the Intentional dimension was realised depending on how each participant team chose to align the affordances of the simulation as an interactive instructional tool with the content-specific learning goals in the design of the lesson activities. For example, with the lesson designed by DTB2 on the topic: "Frictional force", the diagnosis element of the Intentional dimension seemed to be more pronounced). The lesson plan document (Figure 3) showed evidence of this using the Force and Motion: Basics (Friction*)* PhET simulation environment (Figure 4).


Specific Objectives	By the end of the lesson, the student should be able to: • define frictional force. [1]

Activity 1: Definition of frictional force (25 mins.)
For students to come out with the definition of frictional force in their own words, the teacher puts them in groups of three and guides them to:

- use snapshot from the simulation environment to help students to set up their simulation for activity 1.
- explore the simulation for five minutes.
- observe the simulation on friction as they do the exploration
- A & B — identify the arrows X and Y on the body of mass 50 kg as explored in the simulation.
- A — record the values X and Y as shown on the activity sheet.
- A, B, & C — explain why the body of mass 50 kg do not move when the force X was applied on it.
- D & B — identify the nature of the surface of the floor in contact with the body of mass 50 kg as explored in the simulation.
- define frictional force in their own words.

[1]

Diagnosis

Evaluation

Figure 3. Intentional dimension as projected by DTB2 in their lesson plan document using the Force and Motion: Basics (Friction) PhET simulation.

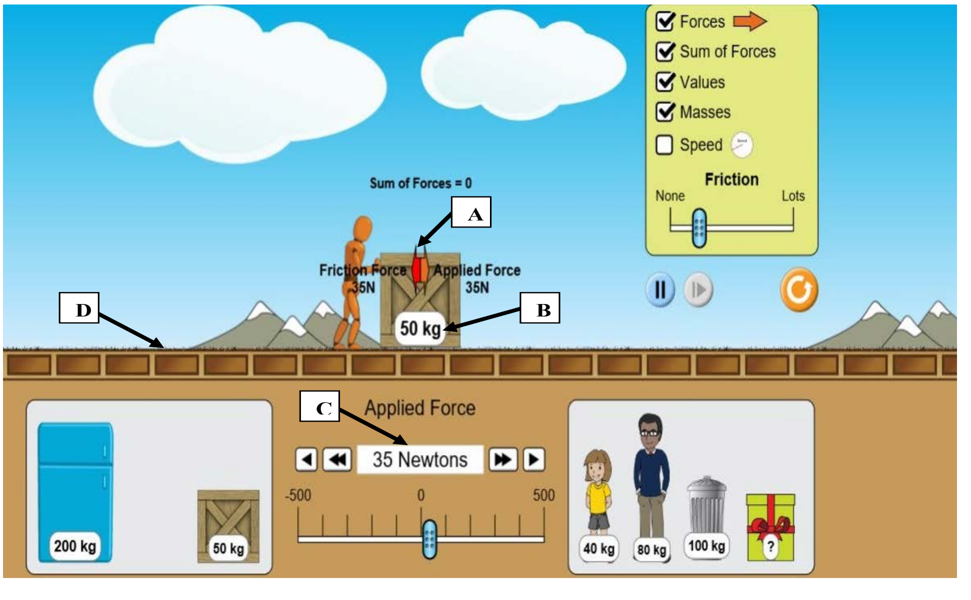


Figure 4. Snapshot of the Force and Motion Basics (Friction) simulation.

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The labels A, B, C and D are added by the researchers for identification of the interactive features of the simulation environment as used by DTB2 in design of Activity 1.

As illustrated in Figure 4, the affordances of the interactive features (i.e., labels A, B, C and D) of the Force and Motion: Basics (Friction) PhET simulation environment were aligned by DTB2 with the various tasks enlisted under Activity 1 in the SBPL_4 lesson plan document. This was purposed to achieve the learning goal set for Activity 1: "Define frictional force" (labelled as 1 in Figure 3). In particular, the left and right directional arrows in Figure 4 (i.e., label A; referred to as X and Y respectively in Figure 3) represent the "Friction Force" and the "Applied Force", respectively; the box with the 50 kg label (i.e., label B) represents a body of mass, 50 kg; label C represents the "Applied Force", with specific values that are regulated either by moving the slider at the bottom or clicking on the forward or backward buttons; label D represents the rough surface on which the weight is placed. It can be inferred from the activities designed (Figure 3) by DTB2 using Force and Motion: Basics (friction) PhET simulation that the learners were engaged more in the diagnosis aspect than the other two aspects of the Intentional dimension in achieving their learning goal of defining frictional force. This seems to suggest that DTB2 in their design of Activity 1 used the diagnosis element as the driving force for bringing to light both the evaluation (i.e., the aspect of Activity 1 in Figure 3 where, learners are tasked to "define frictional force in their own words") and the improvement in the learning gap aspects (i.e., the anticipated learning outcomes for Activity 1) of the Intentional dimension.

Pre-service Teachers' Enforcement of the Cooperative Dimension with Lessons

With the Cooperative dimension, the qualitative evidence showed that the participants used their respective PhET simulation environments to engage students to work in groups for divergent knowledge expressions, where they shared ideas about the various physics concepts that were taught. **S**ome of the evidence in this regard resulted from the FGIs conducted after each microteaching try-out session. For example, from the FGI conducted after Kwesi had taught his team's lesson (SBPL_1) on the topic: "Reflection and Refraction of light" to the other participants, Kwesi explained in response to the question, "*To what extent did the intervention promote interactivity during the lesson?*" that:

> I asked them to work in groups, so it was really interactive.

Apparently, Kwesi perceived the simulation-based lesson to be interactive because he, in his capacity as the teacher, instructed the learners to work in groups during the lesson. In response to the same question, Kwame and Kwabena, who posed as learners during Kwesi's teaching with the SBPL_1 intervention, supported Kwesi's view by adding that:

> We interacted with our colleagues during the lesson. (Kwame).

> We shared ideas with our colleagues during our work, so there was this cooperative element. (Kwabena).

The lesson plan documents designed and developed by all the teams as part of the lesson artefacts for their respective SBPLs shed more light on the results from the FGI data (see Figure 5). Figure 5 suggests that per the stipulated "attitudes" required of the learners for effective learning of the subject matter using the PhET simulations, the participants envisioned the groupwork element as a necessary condition (though not sufficient) for bringing about interactive teaching and learning throughout their respective lessons. Figure 5 also suggests that the Cooperative dimension was not only incorporated for facilitating divergent knowledge expressions (as the FGI data suggested), but was also situated throughout the designed lesson activities as the sustaining element for the realisation of each of the four other dimensions (i.e., Active, Constructive, Authentic, and Intentional). Thus, it appears that the Cooperative dimension's position as the sustaining element in the design of the simulation-based lesson activities served as the basis for motivating the learners to do the lesson activities.

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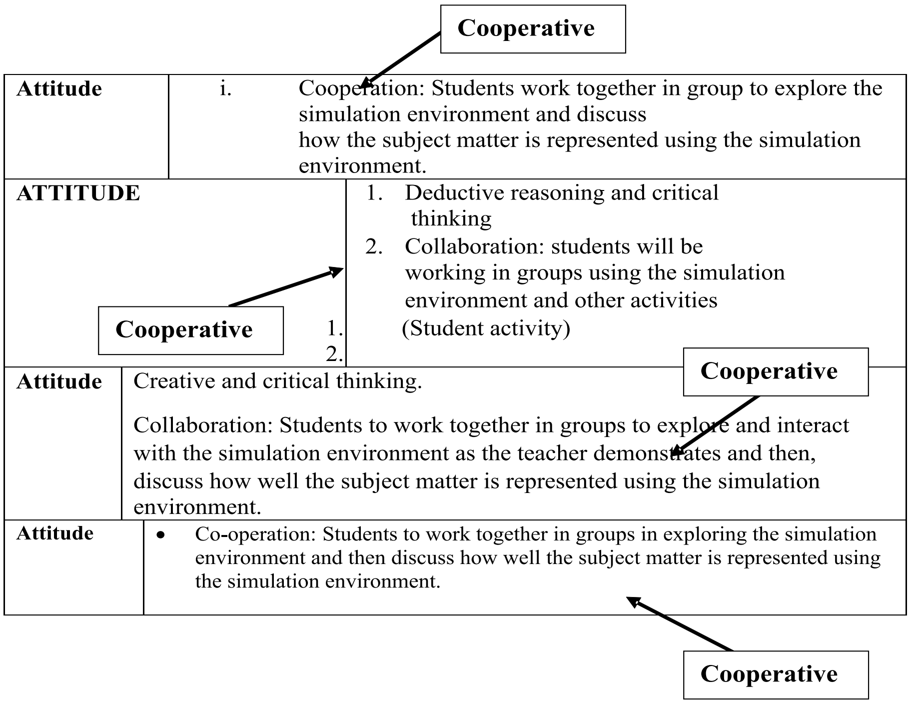

Figure 5. Projection of the Cooperative dimension in lesson plan documents.

Pre-service Teachers' Overall Perceptions about the Effectiveness of the SBPLs

The effectiveness of the simulation-based lessons was also determined quantitatively from the analysis of the Five-dimension Survey. Analysis in this regard corroborated the qualitative evidence. Figure 6 provides an overview of the overall ratings of the dimensions of interactivity as perceived by the participants. The overall picture, as depicted by Figure 6, points to the fact that the Cooperative dimension was the most projected in participants' lessons; using PhET simulations to engage students in groupwork for divergent knowledge expressions. A possible reason for this could perhaps be because the Cooperative dimension was situated as a pre-requisite for the execution of all the lesson activities for each of the four lessons, irrespective of the dimension(s) (Active, Constructive, Intentional, and/or Authentic) the activities were designed to realise. The second most projected dimension was Constructive, with the Intentional dimension emerging third, while the least projected was the Active dimension.

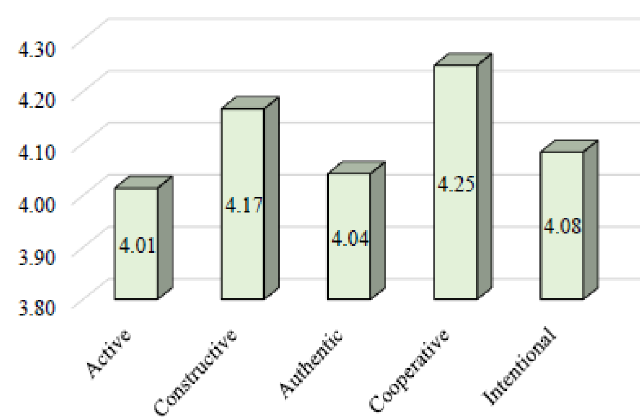

Figure 6. Overall means of the Five-dimension survey as expressed by participants for all four simulation-based physics lessons designed and enacted.

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In all, both qualitative and quantitative results presented echo that all the dimensions of interactivity were adequately realised in the design and implementation of the SBPLs. This seems to be an indication that the ICT (simulation)-based lessons were effective in promoting interactive teaching of physics.

Discussion

The research examined the effectiveness of SBPLs in improving the teaching of physics by measuring the extent to which the dimensions of interactivity were realised in the design and implementation of the SBPLs. The overall results (from both qualitative; see Table 3, Table 4, Table 5, Figure 3, Figure 4 and Figure 5 and quantitative; Figure 6) suggest that the pre-service teacher participants believed that the lessons (SBPLs) were effective in improving teaching because it promoted interactive teaching. Apparently, the selected PhET simulations were used in the design and implementation of the all the four simulation-based lessons to: 1) engage learners in learning the subject matter (Active); 2) stimulate learners to go beyond reflecting on the subject matter to forming and expressing their own personal meaning of the subject matter (Constructive); 3) create learning platforms in order to link learners' personal experiences in learning the subject matter to the real-world (Authentic); 4) engage learners in diagnosis, evaluation, and improvement of learning gaps by aligning the affordances of selected PhET simulations with content-specific learning goals in the design of lesson activities (Intentional); and 5) engage learners to work in groups for ascertaining divergent knowledge expressions (Cooperative). Results herein seem to emphasise the fact that the PhETs' use for the design and implementation of the ICT-based physics lessons by the participants tended to promote the teaching of physics to be effective in a constructivist way owing to its vehicular and rich catalytic characteristics as an interactive tool (Howland et al., 2012; Volman, 2005).This seems to reflect Sahin's (2006) view that the pedagogical approach to be adopted with simulations could be constructive where the focus is on elements such as experiencing, integrating and conceptual change. The results are also consistent with Bell and Smetana's (2008) observation that when simulations are used for teaching purposes, its effectiveness is highly and inevitably dependent on the way and manner in which it is used in the classroom (Bransford, Brown & Cocking, 2000). This suggests that the pedagogical approach adopted for ICT use in the classroom is key to yielding meaningful learning outcomes.

The projection of the Active, Constructive, Authentic, Intentional and Cooperative dimensions of interactivity in the developed and implemented SBPLs also suggests that the pre-service teacher participants used the PhET simulation environments to promote a highly student-oriented learning process (Hofstein & Lunetta, 2003). This seems to be an indication that the ICT (simulation)-based lessons facilitated improvement in the participants' way of teaching from a teacher-centred approach to a learner-centred approach.

The results indicating that the lessons were effective in promoting interactive teaching also advocate that the five dimensions for meaningful learning were not realised in isolation for interactive teaching (i.e., improvement in teaching) to be achieved. It appears that it was more of the combined effect of all the dimensions in each of the developed and enacted simulation-based lessons that provoked interactive teaching. This seems to emphasise the specific ways in which the pre-service teacher participants used the PhET simulations to bring into action the prospects of interactive teaching for meaningful learning to occur. This is consistent with Ertmer and Ottenbreit-Leftwich's (2010, p. 260) statement that "to use technology to support meaningful student learning, teachers need … the pedagogical methods that facilitate student learning, and the specific ways in which technology can support those methods". The results also align with Jonassen et al.'s (2008, p. 3) assertion that "… instructional activities should engage and support combinations of active, constructive, intentional, authentic, and cooperative learning because they are synergetic". The results herein therefore project the synergetic (or systemic) effect of the five dimensions as an essential and necessary ingredient for effective teaching and learning processes with ICT.

Although the results seem to suggest that a combination of all five dimensions was key to attaining interactivity with each of the SBPLs, their unique contributions as perceived and demonstrated by the pre-service teacher participants seemed to differ from one dimension to the other. This was particularly so for the Cooperative dimension, which was most projected (see Figure 6). Apparently, the participants might have linked their understanding of interactivity more to the Cooperative dimension than the other four dimensions. Perhaps this was due to its use in the design and enactment of the lessons as a sustaining element (i.e., the necessary condition) for ensuring that lesson activities were executed in diverse ways to promote interactive

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teaching, irrespective of which dimension(s) the lesson activities were specifically purposed to project. This suggests that the Cooperative dimension goes beyond providing platforms for divergent tasks as well as knowledge expressions (Harris et al., 2009) to inherently sustain the other four dimensions in order to facilitate the creation of an interactive teaching and learner-centred environment mediated by ICT; especially simulations.

Another dimension that was noticeable was the Active dimension (see Figure 6). Unlike the Cooperative dimension which was perceived as the highest projected dimension among all the other dimensions in realising interactivity, the Active dimension was perceived as the least projected. It is not clear what might have accounted for the reported least projection of the Active dimension. However, it appears that the participants might have misconstrued the Active dimension to imply Constructive. Perhaps, this was so because the simulation-based activities that the participants had designed to engage learners in learning the subject matter tended to provoke the learners to express their ideas and make meaning of the subject matter beyond what had been presented to them by the 'teacher' (Jonassen et al., 2008), as the results from Table 3 suggest. In this regard, the potential of computer simulations to facilitate knowledge construction by actively involving the learner (Yin, Song, Tabata, Ogata, & Hwang, 2013) is emphasised, contrary to Koh's (2013, p. 887) assertion that "being does not necessarily imply being constructive". The Active dimension appearing as the least projected dimension also speaks to the challenge that the pre-service teacher participants of the study might have faced in the design and implementation of the SBPLs. This could be interpreted to mean that they might have had difficulties in clearly distinguishing between the Active and Constructive dimensions of meaningful learning (interactivity). The results herein thus, reiterate the need to clearly elucidate how ICT defines the Constructive dimension by making use of the Active dimension (Koh, 2013).

Based on the results of the study, the following propositions are suggested:

- Institutions mandated to train pre-service teachers should consider adopting the PhET simulations as one of the major technological tools in the preparation of pre-service teachers for their uptake of ICT in the teaching of high school physics in Ghana.
- In-service training programmes for practicing physics teachers at the high schools should be organised to incorporate the use of PhET simulations in developing their competencies to use ICT to teach high school physics. The essence of this initiative would be to promote interactive teaching of high school physics in Ghana. This would also serve as a remedy for reducing the current teacher-centered approaches being adopted for teaching physics as well as curbing the problem of learner understanding and performance in physics in Ghana.

The study outcomes also highlight issues that need to be considered in any attempt to adopt the 5DML-ICT model as a whole and to operationalise its Active and Cooperative dimensions. These issues include:

- Designing ICT-based lessons to uniquely project the synergetic (or systemic) effect of all the dimensions of the 5DML-ICT model.
- Characterising the Cooperative dimension in the design of ICT-based lesson activities to bring to light its characteristic potential as a sustaining element for the remaining four dimensions of the 5DML-ICT model.
- Characterising the Active dimension in the design process in such a manner that its relationship with the Constructive dimension of interactivity is clearly defined.

Conclusions

The research articulated the diverse ways in which the teaching of physics improved using the SBPLs. Through the realisation of all the five dimensions of interactivity in the design and implementation of the SBPLs, the results showed that the SBPLs promoted interactive teaching and thus, were effective in improving the teaching of high school physics. The research also identified the Cooperative dimension as the most projected dimension of interactivity for bringing to light the synergetic effect characteristic of the 5DML-ICT model. This was attributed to its potential to sustain the other dimensions. Based on these outcomes, the study suggests that the SBPLs are beneficial for effective teaching of high school physics. As the results of the research situated the synergetic (or systemic) effect of the dimensions of interactivity as an essential and necessary ingredient for the effective teaching and learning processes with ICT, the research advocates that

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the effectiveness of simulation-based lessons in the physics classroom is mainly driven and sustained by the collaborative platforms that are created in enforcing an interactive and learner-centred teaching strategy.

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