

**TRACKING THE DEVELOPMENT OF PRE-SERVICE TEACHERS' COMPETENCIES  
FOR INTEGRATING INFORMATION AND COMMUNICATION TECHNOLOGY IN THE  
TEACHING OF HIGH SCHOOL PHYSICS IN GHANA**

**BY**

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## DECLARATION

I, Elizabeth Darko Agyei, declare that the Doctoral Degree research thesis:

**TRACKING THE DEVELOPMENT OF PRE-SERVICE TEACHERS' COMPETENCIES FOR INTEGRATING INFORMATION AND COMMUNICATION TECHNOLOGY IN THE TEACHING OF HIGH SCHOOL PHYSICS IN GHANA**, that I herewith submit for the

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E DARKO AGYEI

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DATE

## **DEDICATION**

I dedicate this PhD thesis to my “Dearest In my Own Heart”, Douglas Darko Agyei. His love, support, sacrifices, and confidence in me against all odds is what has brought me to this successful end.

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## ABSTRACT

The study used a Design-Based Research approach with an explanatory case study design to track and understand the process of development of pre-service teachers' competencies for integrating information and communication technologies (ICTs) in the teaching and learning of high school physics in Ghana. To achieve this goal, Physics Education Technology (PhET) simulation was used as an interactive tool by which the study sought to: 1) produce an ICT-based intervention that fits the Ghanaian senior high school physics classroom context; 2) examine the effectiveness of the ICT intervention; and 3) provide explanations on how and why improvements in teaching using ICTs and enhanced students' learning of physics concepts through the implementation processes are possible. Seventeen pre-service physics teachers from the University of Cape Coast, Ghana participated in the study – eight of them (in their 3<sup>rd</sup> and 4<sup>th</sup> years) were the competencies understudy while the remaining nine pre-service teachers (2<sup>nd</sup> years) only served as “learners” to mimic the roles of high school students. The eight competencies understudy were enrolled in a professional development arrangement to develop their competencies in using PhET simulations to teach high school physics in an interactive and learner-centred manner. Based on the experiences gained through the professional development arrangement, this group of pre-service teachers collaborated to design PhET simulation-supported lessons in Design Teams and afterwards, enacted the intervention in two try-outs of microteaching among themselves and their peers who only served as “learners” in the study. Questionnaires, observations, semi-structured interviews, focus group discussions, pre- and post-tests, and lesson artefacts developed by the pre-service teachers were the data sources employed in this study. The findings of the study revealed that the ICT-based intervention promoted learner-centred and interactive teaching of physics based on its inherent characteristics. The study therefore suggests that the intervention developed herein signifies the kind of ICT intervention that fits the realities in the senior high school physics classrooms in Ghana. The results also showed that the pre-service teachers improved in their teaching practices with the ICT-based intervention owing to their developed technological pedagogical and content knowledge; improved content knowledge; and developed competencies in the exploration

of the PhET simulations. The PhET simulations as an interactive ICT tool was revealed to facilitate enhanced students' learning of concepts in physics, motivate students' interest in physics as a science subject as well as promote meaningful learning when used for physics instruction. Central to these findings herein is the professional development arrangement considered for the study. The specific features of the professional development arrangement that matter for the development of pre-service teachers' competencies for integrating ICT in the teaching of physics as well as the implications of the findings of this study are discussed.

**Keywords:** Information and Communication Technology; Design-Based Research; Design Teams; High School; Physics; Simulations; Competencies; Interactive teaching.

## **AWARD**

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## ACRONYMS

B.Ed.	BACHELOR OF EDUCATION
BA	BUILD AN ATOM
BL	BENDING LIGHT
CK	CONTENT KNOWLEDGE
CRDD	CURRICULUM RESEARCH AND DEVELOPMENT DIVISION
DBR	DESIGN-BASED RESEARCH
DOS	DEFORMATION OF SOLIDS
5DML-ICT	FIVE DIMENSIONS FOR MEANINGFUL LEARNING WITH INFORMATION AND COMMUNICATION TECHNOLOGY
DT	DESIGN TEAM (S)
DTD	DESIGN TEAM DESIGNATION
FF	FRICTIONAL FORCE
GO	GEOMETRIC OPTICS
GPC4SHS	GHANAIAN PHYSICS CURRICULUM FOR SENIOR HIGH SCHOOL
GSHSPC	GHANAIAN SENIOR HIGH SCHOOL PHYSICS CLASSROOM
ICT	INFORMATION AND COMMUNICATION TECHNOLOGY
ICTs	INFORMATION AND COMMUNICATION TECHNOLOGIES
ICT4AD	INFORMATION AND COMMUNICATION TECHNOLOGY FOR ACCELERATED DEVELOPMENT
ILOs	INTERACTIVE LEARNING OBJECTIVES
MBL	MICROCOMPUTER-BASED LABORATORY
MOE	MINISTRY OF EDUCATION
PCK	PEDAGOGICAL CONTENT KNOWLEDGE
PDA	PROFESSIONAL DEVELOPMENT ARRANGEMENT
PhET	PHYSICS EDUCATION TECNOLOGY
PhETs	PHYSICS EDUCATION TECHNOLOGY SIMULATIONS
PK	PEDAGOGICAL KNOWLEDGE

PSSPL	PhET SIMULATIONS-SUPPORTED PHYSICS LESSON
PSSPLs	PhET SIMULATIONS-SUPPORTED PHYSICS LESSONS
PV	PHOTOVOLTAIC
RQ	RESEARCH QUESTION
SHS	SENIOR HIGH SCHOOL
SSSCE	SENIOR SECONDARY SCHOOL CERTIFICATE EXAMINATION
TCK	TECHNOLOGICAL CONTENT KNOWLEDGE
TK	TECHNOLOGICAL KNOWLEDGE
TPACK	TECHNOLOGICAL PEDAGOGICAL AND CONTENT KNOWLEDGE
TPACK-5DML	TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE AND THE FIVE DIMENSIONS FOR MEANINGFUL LEARNING WITH INFORMATION AND COMMUNICATION TECHNOLOGY
TPK	TECHNOLOGICAL PEDAGOGICAL KNOWLEDGE
TS	TECHNICAL SCHOOL
UCC	UNIVERSITY OF CAPE COAST
UEW	UNIVERSITY OF EDUCATION, WINNEBA
VA	VIDEO ANALYSIS
WAEC	WEST AFRICAN EXAMINATION COUNCIL
WASSCE	WEST AFRICAN SENIOR SECONDARY CERTIFICATE EXAMINATION
WS	WAVES ON STRING

# **1. CHAPTER 1: ORIENTATION AND BACKGROUND OF THE STUDY**

## **1.0. Introduction**

This chapter gives an overview of the current study under the subheadings: Background of the study, Purpose and significance of the study, Research questions, Objectives of the study, Theoretical framework, Research design and research methodology, Limitations of the study, Delimitation of the study, and Value for the study. A section, namely; “Definition of terms” is also provided to give meaning to the various terms used in the thesis. A summary is also provided at the end of this chapter.

In the current section, I give a brief account of the context of the study in order to establish the need for the research.

In Ghana, physics is taught at the senior high school level as an elective science subject. It is a requirement for tertiary education programmes such as medicine, electrical engineering, and nursing. Students are expected to obtain a good pass mark in the West African Senior Secondary Certificate Examination [WASSCE] (i.e., Grade: A1-C6) or Senior Secondary School Certificate Examination [SSSCE] (Grade: A-D) as well as have a solid foundation in physics at senior secondary school to enter tertiary level science related programmes (Buabeng, Ossei-Anto & Ampiah, 2014). Unfortunately, the achievement level of high school physics students in Ghana has been described as poor (WAEC, 2010). The poor performance in physics has therefore become an issue of great concern not only in Ghana but internationally (Buabeng, Ossei-Anto, & Ampiah, 2014; Grande, Tevar, Miranda & Reyes, 2008; Shamim, Rashid & Rashid, 2013). Different explanations for the low achievement in physics have been advanced, among which is the teaching factor (Adeyemo, 2010; Buabeng & Ntow, 2010; Njiru & Karuku, 2015). Buabeng and Ntow (2010) argued that for most students, the method of instruction used by physics teachers is the source of their inability to perform well. In Kenya, Njiru and Karuku (2015:381) identified the teaching factors such as “quality of teacher-student interactions and teacher’s content knowledge” as contributing factors to students’ low

performance in physics. Antwi, Anderson and Sakyi-Hagan (2015) also identified the lecture method as a contributing factor to the difficulty perceived by students and as such, the cause of the poor performance in physics. Evidently, physics is not being taught in ways that are interesting, interactive, and learner-centred at the high school level. Hence, to obtain better achievements in physics, a substantive change in the teachers' methods of teaching is required (Wanbugu & Changeiywo, 2008). This is articulated more clearly in the Ghanaian high school physics curriculum which advises teachers to "avoid using rote learning and drill-oriented teaching methods" (Ministry of Education [MOE], 2010). Teaching strategies that promote critical and scientific thinking are highly recommended in the Ghana education reform document (MOE, 2007). Such approaches include participatory teaching and learning, inquiry-based learning, and active learning (MOE, 2008). Hence, the importance of information and communication technology (ICT)-rich teaching and learning environments and the teachers' role as a facilitator is of much interest to the government of Ghana (Ghana ICT for Accelerated Development [ICT4AD] Policy, 2003). The traditional approach for teaching physics may not reflect what is required in the curriculum. However, the teachers in question are usually constrained in identifying the most appropriate resources required to teach physics by themselves. Intervention initiatives to assist teachers in identifying the best approaches to teach the subject are required. Furthermore, many of the teachers are also not as strong in their knowledge of and/or experience with alternative teaching approaches and resources required to improve student learning in physics (Adegbenro, Gumbo & Olakanmi, 2017; Webb & Cox, 2004).

ICT is often noted as an important way of addressing some of the challenges to the teaching of physics (Su, 2008) as it has much to offer in making the teaching of physics interactive. Studies on ICT integration in science have highlighted the fact that ICT-based resources (e.g., simulations) have potentials that allow for: learners to explore through their own inquiry—forming a sharp mental framework (Adams, Paulson & Wieman, 2008); improvements in students' understanding of concepts in physics (Zacharia & Olympiou, 2011. de Jong (2010) explains that ICT-based resources (e.g., simulations) have potentials that allow for student-centred learning and afford teachers the opportunity to be facilitators in the classroom. The potentials of ICT for the teaching of science have

been realised in many countries (Barton, 2004; Reid, Burn & Parker, 2002). For example, Microcomputer-based laboratory (MBL) is noted as one of the earlier ICT tools integrated into science lessons in the United States of America (USA) (Hogarth, Benneth, Lubben, Campell & Robinson, 2006). MBL has been used for teaching science not only in the USA but also in other less developed countries. A study conducted in Tanzania by Voogt, Tilya and Van den Akker (2009:429) showed that MBL supports a student-centred approach of teaching in ways that make science experiments “investigative and open-ended”. Furthermore, the affordances of ICT have been explored in literature for different science subjects (biology, chemistry and physics) to facilitate knowledge construction based on students’ experience (Chang, 2001; Huffman, Goldberg & Michlin, 2003), to promote scientific inquiry (Dimitrov, McGee & Howard, 2002); and to enhance students’ conceptual understanding (Barak & Dori, 2005). Thus, ICT may represent a progressive alternative solution to the poor performance in physics.

Many countries in Africa; the Republic of Ghana included, however, are yet to exhaust the potentials that ICT affords in addressing the issue of poor performance in physics at high school. Furthermore, not enough research has been done to explore ICT as an interactive physics instructional tool despite the government of Ghana’s initiative to develop a highly interactive teaching and learning atmosphere that is ICT-driven (MOE, 2015). The few studies on the integration of ICT in relation to physics instruction in Ghana have explored physics teaching at university level (Antwi, 2013). Hence, a study that explores how ICT can be used to facilitate the creation of interactive environments for effective teaching and learning of physics at high school level in Ghana is essential.

## **1.1. Background of the study**

The role physics plays in the development of a nation cannot be underestimated owing to its remarkable applications; on the basis of which, the world survives in terms of productivity, economic, technological and industrial development (Buabeng, Ossei-Anto & Ampiah, 2014; Murei, 2015; National Academy of Sciences, 2008; Zhaoyao, 2002). In addition, physics has a broad spectrum of applications that rule our world today; for

example, developments in the knowledge of Electricity and Magnetism have brought immense technological development in all fields of physics. The design of generators and motors using the phenomena of electromagnetic induction for example are widely used mechanical and electrical devices. Fibers as used in optics form the backbone of many communication systems. Photovoltaic (PV) technology which involves harnessing solar energy by use of either organic or inorganic materials is an application of physics that could reduce the world's reliance on fossil fuel. That notwithstanding, the PV technology as an application of physics could serve as alternative solution to energy crisis in many countries such as Ghana. Hence, physics is an indispensable tool for national development. All these applications among others, bring us to the realisation that to thrive in the present demanding technological world, every country including Ghana must attain a certain level of education with majority of the population scientifically inclined to affect the nation positively in order to grow. In addition, policies need to be enacted and resources made available to support such an agenda in order to improve literacy in science and physics to be specific. Adequate and proficient measures must also be taken to make physics more practicable and interesting in the classroom in order to subdue the traditional approach mostly used in Africa (for example, in Ghana); where learning seems to be the job of the teacher without any active role on the part of the students (Voogt, 2003).

Physics as a subject, though described as a fundamental science in general, is mostly perceived to be a difficult science especially at the high school level of education. There are several reasons to this perception. These may include students' personal understanding of physics (Gray, Adams, Wieman & Perkins, 2008); the method of instructions being used in teaching the subject (Azure, 2015; Buabeng, 2012; Donnellan, 2003); and to a large extent, the mathematics required for solving problems in physics (Taale, 2011). Behar and Polat (2007) also added misconception as a contributing factor to the difficulty of certain science (physics) topics which could result from students' personal experiences (Martin, Sexton & Gerlovich, 2002). Misconception in this regard, calls for efficient ways of teaching science subjects like physics (Thompson & Logue, 2006) and also, highlights the need for relevant and/or suitable teaching methods to be adopted for the purpose of clearing students' misconceptions about physics and science

in general. The method of instruction employed by teachers in the physics classroom seems to be a major drawback as far as physics education at the Senior High Schools (SHSs) is concerned particularly in Ghana (Antwi, Anderson & Sakyi-Hagan, 2015; Azure, 2015). For example, Antwi et al. (2015) emphasised the need for a solution to the problem with current methods of instruction being used to teach science in the SHSs in Ghana. According to these authors, the lecture method is the dominantly used instructional method for teaching science of which, physics is part. Consequently, the learners' loose interest in the subject as they are not given the chance to participate actively. Moreover, in most Ghanaian classrooms, the mode of instruction takes the form of teacher-centred approaches rather than an effective method of inquiry (Buabeng et al., 2014; Bybee, Trowbridge & Powell, 2008; Ottevanger, van den Akker & de Feiter, 2007). If these problems are to be addressed, then there is need to develop science teachers' (both in-service and pre-service) competencies for adopting effective instructional approaches (Kelly & Staver, 2005) that are learner-centred and also, promote students' interest, understanding (Korur & Eryilmaz, 2012) and motivation through effective method of inquiry. Consequently, an understanding of the process involved in enhancing teachers' capabilities to become effective, interactive and learner-centred (taking into consideration the specific type of knowledge they would require to drive the effective and interactive instructional approach) cannot be overlooked. On these grounds, of keen interest for the current research was to study and gain understanding into the development of pre-service teachers as they develop their competencies in using ICT for teaching physics in ways that are interactive and student-driven. This was meant to gain deeper insights into how and why improvements in teaching of physics using ICTs through the implementation process could be achieved.

## **1.2. Purpose and significance of study**

Despite several attempts to improve physics, the achievement level of students taking physics as an elective subject at the SHSs in Ghana is still very low (WAEC, 2005, 2006, 2009 and 2010). For example, WAEC (2005:259) indicated that "quite a number of

candidates could not solve mathematical-related problems accurately". The report for WAEC, (2009:376) also stated that "poor knowledge of subject matter, inadequate preparation and poor labelling of diagrams were some of the weaknesses that adversely affected candidates' performance" and this, as mentioned earlier has become an issue of great concern to stake holders of education in Ghana (Buabeng, Ossei-Anto, & Ampiah, 2014). Buabeng and Ntow (2010) pointed teacher factor among others, as one of the perceived reasons for the low achievement in physics. Their work revealed that for most students, the method of instruction being employed by teachers to teach physics was the source of their inability to perform better. This confirms that the teaching strategy being adopted for physics at the SHSs in Ghana is a major cause for the recorded poor performances and reduced interest in physics. Ottevanger et al. (2007) indicated that the teacher-dominated teaching approach, though it does not promote the learner to be active, it is the way of teaching science in Ghana. These arguments therefore suggest that physics is made non-interactive in the Ghanaian classroom in spite of many initiatives by the Government of the Republic of Ghana to transform the current teaching practices to more learner-centred methods that involve the creation of a highly interactive teaching and learning environment. Thus, the need for emphasis on the teaching of physics in a way that would be very interactive in order to enhance students' understanding of the subject. This, however, should not be of key interest only to the Government, but also to both physics educators and researchers.

Several studies highlight the impact of ICT use in providing an interactive environment as well as developing students' conceptual understanding and achievement of physics (e.g., Antimirmova & Miller-Bolotin, 2009; Sokoloff, Thornton & Laws, 2004; Wieman, Perkins & Adams, 2008). These studies highlight ICT tools such as spreadsheet, microcomputer-based laboratories (MBL), video analysis (VA), and simulations as useful and interactive tools for the teaching of physics. An ICT tool like simulations is highly recommended as an interactive tool in literature (Wieman & Perkins, 2005) for the creation of interactive learning environments. According to Wieman et al. (2008), simulations have the potential to provoke students to think deep into the concepts they are being taught and also, allow them the opportunity to understand abstract concepts in physics. Furthermore, with a technological tool like simulations, the essence of ICT in teaching physics is brought to

bear for the development of strong conceptual understanding in various topics in physics, piquing the interest of students towards the subject, and most certainly, promoting constructiveness in physics classrooms in such a manner that provokes good achievement levels in the subject. In Ghana as mentioned earlier, these potentials that ICTs especially, simulations afford in making the teaching of physics at the SHS level less abstract and more interactive seem not to have been adequately explored.

A few research studies have examined interactive teaching of physics in Ghana. These however, have not been peculiar to the context of senior high school level of education in Ghana. For example, a study conducted by Antwi (2013) on interactive teaching of mechanics sought to develop physics teaching strategies for the Ghanaian university context with a focus on promoting active participation on the part of students in a meaningful teaching and learning process. Apart from the fact that Antwi's (2013) work was conducted to fit the university context, the study explored little on using ICT as a resource for making mechanics (physics) interactive. This certainly leaves room for further research that would explore the potentials that ICT brings on board in making mechanics as well as other topics in physics interactive not only at the university, but also at the SHS level of education in Ghana. In this study, the enormous potentials that ICT affords in enabling interactive teaching and learning of physics were explored specifically for the Ghanaian senior high school context.

### **1.3. Research questions**

The main research question was: How can the process of development of pre-service teachers' competencies for integrating ICT in the teaching and learning of high school physics in Ghana be understood using simulations as an interactive tool. To answer the main research question, the following sub questions were considered:

- What ICT intervention can be designed to fit the realities in the SHS classroom in a manner that makes the teaching of physics interactive in Ghana?
- How effective is the ICT intervention in improving teaching and enhancing students' learning of concepts in physics?

- How can the improvements in teaching using ICTs and enhanced students' learning of physics concepts be understood and/or explained?

#### **1.4. Objectives of the study**

The overall goal of this study was to explore and understand the process of development of pre-service teachers' competencies for integrating ICT in the teaching and learning of high school physics in Ghana, using simulations as an interactive ICT tool. The specific objectives for achieving the overall goal was to:

1. determine the features of an intervention that best fit the realities in the SHSs that can prepare pre-service teachers to effectively design and implement ICT using simulations as an interactive tool in teaching physics for the enhancement of students learning outcomes in Ghana.
2. produce an effective ICT intervention for interactive teaching of physics and also for enhancing students' understanding of various concepts of physics in Ghana.
3. provide an explanation and/or account of how and why improvements in teaching using ICTs and enhanced students' learning of physics concepts through the implementation processes are possible.

#### **1.5. Theoretical framework**

The major concerns that have informed the present study, include poor performances in physics, non-interactive teaching approaches being adopted for teaching the subject, and lack of ICT-oriented knowledge and skills required for effective teaching of physics at the SHSs in Ghana (Azure, 2015; Buabeng et al., 2014; Buabeng & Ntow, 2010). These concerns seem to suggest that the current teaching practices being adopted in the Ghanaian science classrooms for teaching physics are purely teacher-centred. Thus, the study sought to promote interactive teaching of physics with simulations at the SHSs in Ghana with the goal to transform physics education from teacher-centred (traditional)

behavioristic to a learner-centred constructivist model on the basis that learning does not position the teacher to be “all-knowing” whereby he/she transmits the knowledge to students, rather learning should be authentic and learner-centred (Voogt, 2003). Simulations as an ICT tool seems suitable as a medium of instruction for the understanding and employment of the emerging pedagogy of constructivism as noted by Voogt (2003). Thus, by making constructivism the overarching theory for the proposed study, pre-service teachers’ experience in developing ICT-based activities and implementing it in a constructivist manner were explored. Also, the study used constructivism as the overarching theory to underpin the idea of interactivity in the physics classroom. Furthermore, the study combined two theories: “technological pedagogical content knowledge (TPACK)” by Mishra and Koehler (2006) and the “five dimensions for meaningful learning with ICT” (i.e., *Active, Constructive, Authentic, Intentional and Cooperative*) by Howland, Jonassen and Marra (2012) as adapted by Koh (2013). TPACK was used on the basis that teachers need some kind of ICT-oriented knowledge to ensure interactive teaching and learning of physics with simulations at the SHSs. In this regard, TPACK is the knowledge that the teachers need to drive the interactive prospects with ICT (simulations), design and implement simulations-supported lesson materials for physics. The five dimensions for meaningful learning with ICT framework as adapted by Koh (2013) was therefore used as a lens to characterise and define interactive teaching and learning of physics with ICT (simulations). In the next chapter of this thesis, a detailed description of the aforementioned theories is discussed extensively.

## **1.6. Research design and research methodology**

A Design-Based Research (DBR) approach was used in conducting this research. DBR is described as a research approach that has the capacity to establish a link between theory and practice in education (Dolmans & Tigelaar, 2012) placing weight on an iterative process that goes beyond the development of an innovative intervention to refine the invention systematically while producing design principles to serve as a bench for further research endeavours (Amiel & Reeves, 2008). To achieve this, an effective instructional intervention was produced to provide a realistic solution to the non-interactive methods

of instruction being adopted for the teaching of physics in Ghana. This was realised using Reeve's (2006) stages of a Design-Based Research which was adopted and modified to include three stages: a design stage, an implementation and evaluation stage, and a reflection and documentation stage.

The design stage involved the review of literature in order to come up with initial design guidelines. This informed the choice of the appropriate technology (ICT), pedagogy and content for the development of ICT-oriented lessons. The literature reviewed also helped to establish the conceptual framework for the study. Informed by the initial design guidelines, two sets of the designs (ICT (simulations)-based lessons) were produced as the intervention based on the Ghanaian Physics Curriculum for SHS. Experts appraised the intervention to ensure its practicability and improve its validity. The views and suggestions from the experts were then used to improve the quality of the intervention.

During the implementation and evaluation stage, the ICT-based (simulations) lessons designed by the researcher (during the design stage) served as exemplary materials for interactive teaching of physics. I tried out the exemplary materials on two different cohorts of pre-service teachers (these were the competencies understudy) during a session to model and demonstrate ICT use. The try-out on the cohorts was intended to facilitate transfer as well as provide the support needed in developing insights into the underlying principles and conditions for the prospective teachers' application (Agyei & Voogt, 2012). Based on this experience, the first cohort of participants were tasked to develop their own lessons and then try them out in two rounds of microteaching among themselves; that is among their colleague members whose competencies were also understudy (this constituted the first study; that is, Phase 1). In a similar arrangement, a different cohort of participants (also, competencies understudy) were involved in a second study (i.e., Phase 2). In this case, the two rounds of teaching try-outs were done first among the second cohort of pre-service teachers themselves and secondly, among their peers (referred to as "Student peers" in the study) who constituted a different group of pre-service teachers who only served as "learners" to mimic high school students in the study. It is important to mention here that the peers herein were not the competencies understudy though their

views as learners were deemed useful and important for achieving the study's goals. The iterative cycles were meant to help improve the intervention based on the feedback obtained after each try-out.

The final stage (reflection and documentation stage) was for me (the researcher) to go into introspection of the design, development, and try-outs of the intervention in order to gain valuable insights into the process of development of the pre-service teachers in integrating ICT into their teaching practices in an interactive way by use of simulations for meaningful learning outcomes. The proposed study therefore mostly employed the ideas of a qualitative research in a DBR approach with emphasis on a case study design. A case study, in this context served as the underlying approach for providing detailed description of an intervention purposed to solve a particular problem. This type of inquiry was adopted in order to describe the intervention (i.e., simulations-based physics lessons) designed by the pre-service teachers for the provision of an alternative and practical solution to the seemingly non-interactive and purely teacher-centred approaches that are currently being adopted in Ghana for the teaching of physics (Antwi et al., 2015). Furthermore, as the research sought to address an overall research question which was explanatory in nature (Yin, 2003), the type of case study employed was an explanatory case study design. This was considered to be instrumental for achieving the overall goal of the study owing to its remarkable affordances. Explanatory case studies are noted to be vital for exploring and describing a phenomenon, explaining casual relationships and most importantly, developing theory (Harder, 2012); which is a major outcome of the DBR approach used in this study. Its reliance on multiple sources of evidence for the purpose of converging data through triangulation was also considered useful in providing some level of flexibility in arriving at substantive explanations (Yin, 2003). Thus, by this type of case study design, both qualitative and quantitative evidence were employed to effectively realise the ultimate goal of the study; which was, to track and understand the process of development of the pre-service teachers as they developed their competencies in integrating ICT (simulations) as an interactive ICT tool for teaching physics in a learner-centred constructivist manner. Data for the study were collected using semi-structured interviews, observations, focus group discussions/interviews, pre- and

post-tests, questionnaires and the collection of the lesson artefacts (see APPENDICES). This highlights the fact that sources of data collected for the present study were largely qualitative even though, it involved quantitative evidence (e.g., survey).

For quantitative evidence, three different questionnaires (namely, TPACK survey (i.e., TPACK self-assessment instrument), Five-dimension survey and Student peers' survey) were used. The TPACK survey (i.e., pre-post survey) was used purposely to track the change in pre-service teachers' ICT-oriented knowledge. The change was determined by use of a pre-post survey whereby, the same survey instrument was administered twice; before and after the enactment of the intervention (simulations-supported lessons). Hence, in order to track the pre-service teachers' knowledge in relation to ICT integration, items that will allow the pre-service teachers to self-assess themselves towards TPACK were included in the questionnaire. These items were adopted from Schmidt, Baran, Thompson, Mishra, Koehler and Shin (2009a) and modified specifically to address integration of simulations into physics teaching. The Five-dimension survey was employed to measure the extent to which the ICT-based interventions were interactive. Items of this questionnaire were adapted from Koh's (2013:893) "rubric for assessing TPACK for meaningful learning with ICT". This questionnaire was administered only after the intervention had been enacted for the first time. The Student peers' survey was included with the intent to get valuable information from the Student peers who mimicked the real classroom situation for this study by playing the role of SHS science students. In particular, the questionnaire was designed and intended to examine their overall experiences about the ICT (simulations)-based intervention they witnessed in relation to how it enhanced their understanding of concepts in physics. This was meant to corroborate the focus group discussion data collected during the second study.

For the qualitative evidence, the focus group discussion was used to collect data after the first and second teaching try-out sessions in Phase 1 and also, after the first teaching try-out session in Phase 2 where both the first and second cohorts of pre-service teachers taught among themselves. This was done with the intent to identify weaknesses as well as strengths of the interventions and also, give suggestions on the various ways in which

to the intervention could be improved from the perspective of the participating pre-service teachers who were the competencies understudy for this research. The focus group discussion was also used to collect data from the Student peers after the second teaching try-out sessions where the second cohorts of pre-service teachers taught among the Student peers. This was aimed at ascertaining the usefulness of the interventions in enhancing their understanding of concepts in physics as well as learning outcomes.

Semi-structured interviews were conducted to explore the participants' competencies for the design and enactment of the simulations-supported physics lesson artefacts in an interactive manner. This was conducted after each teaching session of the first and second study at the implementation and evaluation stage.

Observation was also central in the data collection. In the process, a researcher's logbook was employed to keep vivid and detailed accounts of the activities and events occurring at the professional development arrangement. Observation was done mainly during the evaluation and implementation stage of the study from design to the enactment of the interventions. Areas of interest that were observed included the appropriateness of the selected simulations for specific topics from the Ghanaian physics curriculum, how the teaching objectives outlined for the designed interventions conformed to the simulations environment employed, how the knowledge of subject matter (physics) was supported by the simulations for each dimension considered, and the teaching approaches adopted in the delivery of the simulations-based lessons.

In the second study where the pre-service teachers enacted the ICT-based lessons among their peers, a test (pre-test) on the physics concepts to be taught was given to the Student peers before the lesson was enacted. After the lesson had been enacted, the same test (post-test) was given to them. This was purposed to measure their understanding of the physics concepts taught using the interventions (simulations-based lessons) and to examine the impact of the simulations-supported physics lessons. In particular, the pre-service teachers designed the test and I reviewed it.

By using the DBR approach with an explanatory case study design, multiple data sources were used for the analysis. Quantitative data collected were analysed using descriptive statistics (i.e., mean and standard deviation) in order to describe the raw data (Creswell, 2014). Qualitative data analysis involved the generation of themes and patterns to make interpretation easier. Document analysis was used to analyse and give meaning to the word-based data gathered from the pre-service teachers' simulations-supported lesson artefacts (i.e., activity sheets, lesson plans and presentation slides). Data collected using semi-structured interviews and focus group discussions were audiotaped and transcribed using a data reduction technique (Miles & Huberman, 1994). Transcription was appropriate for the analysis because it has the means to identify elements that would be missed during the recordings.

In the third chapter of this thesis, a comprehensive account of the research design and methodology is given to throw more light on various research methods, instruments and data collection procedures employed in the study, and how each of the elements involved complimented what the study was purposed to achieve.

### **1.7. Limitations of the study**

In this study, a case study strategy was employed using both quantitative (questionnaires, pre- and post-tests) and qualitative evidence (semi-structured interviews, focus group discussion and observation, researcher's logbook, lesson artefacts). Though each method adopted for data collection has its own inherent errors and limitations which cumulatively may affect few results and conclusions drawn, the different approaches were complementary when triangulated; thereby improving confidence in the findings.

The case study design allowed for only limited number of participants to be used in the current study. Thus, generalising the results to a larger population is not possible. The study however adopted an explanatory type of case study in order to make analytical generalisations that are important for the formulation of design guidelines. The iterative process as afforded by the DBR was upheld to ensure that explanations given in the study were "independent of any methodological biases" (Harder, 2012:3). Data collected from

both quantitative and qualitative evidence were also triangulated to strengthen the veracity of any explanation given (Yin, 2003).

In this study, I assumed a dual role as the researcher and the facilitator during the initial training workshop. I observed the pre-service teachers during their enactment of the interventions they developed and I was also involved in the focus group discussion sessions as I needed to take notes as well as record the proceedings to that effect. Thus, the issue of researcher biases was inevitable. Reflexivity and the use of multiple sources of data therefore provided the basis for resolving this issue through triangulation.

The study was context-bound in that, the pre-service teachers considered for the study were selected from only one higher education institution in Ghana (University of Cape Coast). This could limit transfer of the study to other higher education institutions. The pre-service teachers had physics as their major teaching subject. This placed a limitation on the extent to which data as well as outcomes of the study could be applied to other science subjects such as biology and chemistry and its application.

### **1.8. Delimitation of the study**

In order to work successfully within the limited time, the study selected final year pre-service teachers (for the 2016/2017 academic year) as well as third- and second-years pre-service teachers (for the 2017/2018 academic year) of the Bachelor of Education with specialisation in science (B.Ed. Science) programme at the University of Cape Coast (UCC). These were pre-service teachers who had physics as their teaching subject. The choice of target group or participants had to do with their proximity and availability to me—this made it easier for me to gain an understanding and valuable insights into the context and various problems that came with it. This was key to the ICT integration process during the study and was also, a contributing factor to the smooth data collection process observed. It cannot be established for a fact that the target group was to a larger extent, representative of all pre-service teachers in Ghana owing to the fact that the study was limited to participant from the University of Cape Coast, Ghana. However, the results of the study could be considered for training of: a) prospective physics/science teachers who

are from other teacher education institutions in Ghana as well as other developing countries and b) in-service teachers who lack the knowledge and skills for integrating ICT (simulation) into their teaching practices.

The initial training workshop which involved the third- and second-years pre-service teachers was done in the course of the first semester for the 2017/2018 academic year. Consequently, these pre-service teachers had to attend lectures, write mid semester examinations etc. This posed as a major challenge to the data collection as getting the pre-service teachers to participate in the training session for more than one hour was difficult. Therefore, some of the sessions during the initial training workshop had to be rushed through or cut short to be continued later at the convenient time of these participants.

A few numbers of pre-service teachers who posed as learners during the second phase of the evaluation and implementation stage pulled out of the study due to personal issues. This made the enactment processes with the ICT-based interventions quite challenging. In light of this, the learner-groups that were made up of these group of pre-service teachers (i.e., Student peers) had to be dissolved so that their colleagues who remained could join the other learner-groups.

### **1.9. Value for the study**

The value of this study is to explore and understand the process of development of pre-service teacher's competencies for integrating ICT (simulations) in the teaching of high school physics. Hence, the findings of the study will provide innovative means for generating effective ICT-based interventions for physics as well as exploring the possibilities for creating an interactive teaching and learning environment with simulations.

The formulation of design principles will serve as a lens for understanding the process of development of pre-service teachers' knowledge (TPACK) and skills for integrating ICT in the teaching and learning of high school physics.

The study is also purposed to contribute to scholarship on the teaching of physics in

interactive ways using ICTs in developing countries. In addition, teachers and policymakers will have practical and research-based solutions on the problem of learner understanding and performance in physics.

### **1.10. Definition of key terms**

In the present study, the following terms were used having meanings as stated in this section of chapter one.

**Information and Communication Technology (ICT):** “ICT means the integration of web-based or computer-based technologies such as Word processing packages, Graphical applications, Multimedia” (Agyei, 2012:213), simulations, Data bases, Spreadsheets and any internet activity in the teaching of physics. The specific ICT employed as an interactive tool was simulations.

**Simulations:** A computer program that attempts to mimic an abstract model of a particular system. In this study, targeted simulations (Clark, Nelson, Sengupta, & D’Angelo, 2009) were the class of simulations considered. Targeted simulations were adapted in this study as defined by Rehn et al., (2013) as “... stand-alone simulations designed to cover a particular topic in a scientific discipline” — which is physics in this context. By this definition, the Physics Education Technology (PhET) simulations were the class of targeted simulations considered as the interactive ICT tool employed for the study.

**Interactive teaching:** An instructional method that is learner-centred with teachers’ (both pre-service and in-service) 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 atmosphere.

**Effectiveness/Interactivity:** Refers to the extent to which the “five dimensions for meaningful learning with ICT” (Howland et al., 2012)—*Active, Constructive, Authentic, Intentional, Cooperative* are realised in the design and implementation of the ICT (PhET simulations)-based intervention.

**Pre-service teachers:** Refers to prospective teachers who are still undergoing training to teach at the senior high schools in the near future. In this study, these were undergraduate students at the UCC, Ghana. Two calibers of pre-service teachers were used in the study: participating pre-service teachers who worked directly with the researcher and thus, were the competencies understudy for this research and pre-service teachers who served as learners (high school students) to mimic the real high school classroom situation (namely, Student peers).

**PhET Simulations-Supported Physics Lessons (PSSPLs):** Refers to the ICT based intervention (lesson artefacts) developed in this study by the researcher as the exemplary material and those that the participating pre-service teachers designed based on their experiences with the exemplary material. The lesson artefacts considered in this respect include lesson plan, presentation slides, and activity/work sheets and assignment sheets.

**Technological Pedagogical Content Knowledge (TPACK):** Refers to “the knowledge and understanding of the interplay between content knowledge, pedagogical knowledge and technology knowledge when using technology for teaching and learning” (Agyei 2012:71). In this study, TPACK was specifically considered as the knowledge that teachers need to drive the interactive prospects with ICT (simulations) and also, to design interactive simulations-supported physics lesson materials/artefacts.

**Design Teams:** Refers to “a group of pre-service teachers working collaboratively to design and develop technological solutions for authentic problems they face in teaching” physics “during their in-school training” (adapted form Agyei, 2012:72).

### **1.11. Summary of the chapter**

Discussions presented herein gave an overview of what the present study is about. Specifically, substantive arguments were provided in this chapter to elucidate the current teaching practices—teacher-centred teaching strategy being adopted in the Ghanaian SHS classrooms; appreciate the enormous and interactive potentials of ICT to help bring about a paradigm shift from a teacher-centred teaching approach to a learner-centred constructivist teaching approach; and establish the need for gaining an understanding into the process of development of pre-service teachers' competencies in integrating ICT (simulations) into the teaching of high school physics in the Ghanaian context.

Also, discussions in this chapter have been in relation to the background for the study, the identified problem the study sought to address, the research questions, the objectives, an overview of theoretical framework underpinning the current study as well as the research design and approach employed for the conducting this research work. In particular, a brief description of the stages involved in the DBR approach adapted for the study has also been given in this chapter.

In addition, the present chapter has provided brief information about the limitations and delimitations of the study and also, explained the key terms used in the study as defined to suit the purpose of the study.

In the next chapter, I provide brief background of physics education in Ghana and then, give detailed account of literature reviewed in establishing the theoretical and conceptual framework for the study.

## **2. CHAPTER TWO: LITERATURE REVIEW**

### **2.0. Introduction**

In this chapter, literature is reviewed and discussed in relation to: 1) Physics education in Ghana, 2) the potential of information and communication technology (ICT) in education, and 3) the theories underpinning the present study. The areas of review are discussed in sections and subsections where needed. The section under physics education in Ghana is purposed to give a summary of the education system in Ghana in relation to physics teaching. Also included under this section are two subsections that examine the Ghanaian physics curriculum for Senior High School (SHS) and its implication for teachers, and the nature of the teacher preparation programmes designated for teaching SHS science (physics) in Ghana (including a review on pre-service teachers' competence development in the use of ICTs) respectively. The section that covers the potential of ICT in education has two subsections—one looks at computer simulations in general in light of their potentials for effective teaching of science and physics to be specific; and another consists of review and discussions on Physics Education Technology (PhET) simulations (PhETs). In particular, discussions on the PhETs in this section are geared toward its potential as an interactive ICT tool for teaching high school physics and its appropriateness for use in the Ghanaian context. The third section of the review explores and discusses the theoretical and conceptual frameworks supporting the present study. Three theories are discussed herein: 1) Constructivism, 2) “Technology, pedagogical and content knowledge (TPACK)” framework, and 3) the “five dimensions for meaningful learning with ICT”. These theories, however, constitute the three subsections under this section and are discussed extensively through literature review to give detailed explanations about how each of these theories was conceptualised by me and used to inform the proposed conceptual framework that guided the current research work. This chapter also highlights gaps in the literature reviewed.

## **2.1. Summary of problem statement**

Current approaches for teaching physics in the high schools in Ghana have been described in different terms as teacher-centred and non-interactive (Buabeng, Ossei-Anto & Ampiah, 2014; Antwi et al., 2015; Ottevanger et al., 2007). This seems to be the major barrier to students' understanding of concepts in physics and the development of positive attitudes and perceptions about physics. Literature highlights the potentials of ICT among others to enable students to be authentic in achieving their personal goals, develop critical thinking skills, construct their own knowledge, and to actively interact with teaching and learning materials (Allan, 2007; Fu, 2013; Koh, 2013; Mbodila, Jones & Muhandji, 2013). However, in the Ghanaian context, these potentials, to a large extent, seem not to have been exhausted at all. Thus, the proposed study explored how ICT facilitates effective teaching and learning of physics; purposed to be learner-driven and to stimulate students' interest to improve learning outcomes.

## **2.2. Physics at the senior high school level in Ghana**

In Ghana, "proper" physics education begins at the senior high school (SHS) and the technical school (TS). At the SHS, physics is a compulsory elective subject for the sciences. At the end of the SHS programme, which is purposed for a duration of three years, students are required to write the West African Senior Secondary Certificate Examination. Students are expected to obtain a good pass mark (i.e., Grade: A1-C6) as well as have a solid foundation in physics at SHS to enter tertiary level courses in science (Buabeng et al., 2014). This makes the senior high school physics curriculum an essential component in education at the SHS level in Ghana as it does not only serve as a guide for preparing students for their future studies, but also provides teachers at the SHS level with the necessary information on teaching strategies to adopt in the instructional process.

In the subsection that follows, I discuss in details, the senior high school physics curriculum for Ghana as documented by the Curriculum Research and Development Division (CRDD), Ministry of Education (MOE) of the Republic of Ghana (2010).

### **2.2.1. Ghanaian physics curriculum for SHS (GPC4SHS)**

In Ghana, the Senior High School Physics curriculum is developed and structured to build upon the foundations laid through the Integrated Science subject at the basic level as well as the SHS. The curriculum coverage is very wide as a consequence of which, the syllabus is usually not completed at the SHS due to factors such as insufficient laboratory equipment, quality of teachers, inappropriate teaching methods adopted, etc. (Antwi, 2013).

The GPC4SHS is designed to involve students in activities such as projects, experiments, demonstrations and scientific inquiry with a focus on uncovering the resourcefulness and ingenuity of the physics student and the Ghanaian science student in general (MOE, 2010). This suggests that at the SHS level, physics students are expected to develop valuable knowledge and competencies through their understanding of the physics content taught to enable them to apply it in their day to day activities albeit, solving real life problems; and more importantly, to gain entrance into the tertiary institutions for further study. The curriculum is therefore developed with the intent to equip students with the required basic physics knowledge, skills and appropriate attitudes needed to move the Ghanaian society to meet the challenge of the demanding scientific and technological age of today. Teachers are not left out of the Ghanaian physics curriculum's demands. In relation to their role as implementing agents, there are portions of the curriculum designed and dedicated to guide and advise them on the various strategies to employ for effective teaching of the subject. For example, the GPC4SHS advises teachers to embrace teaching strategies that promote critical and scientific thinking and encourages teachers to "avoid using rote learning and drill-oriented teaching methods" (MOE, 2010: vii). In addition, the curriculum specifies three knowledge dimensions for teaching, learning and testing physics at the SHS. These include "Knowledge and Understanding"; "Application of Knowledge"; and "Practical and Experimental skills" (MOE, 2010: vii). The three dimensions as per the stipulations of the curriculum are meant to promote: 1) meaning making; 2) learning behaviour levels that challenge students to: a) assimilate what they learn to "concrete situations that are new and unfamiliar" (MOE, 2010:viii), b) think critically, c) be creative and d) have an independent mind in order to judge a material on the basis of its worth; and 3) inquiry learning through laboratory investigations

respectively (MOE, 2010). These seem to suggest that the GPC4SHS has been designed purposely to promote student-centred approach to teaching for better learning outcomes. However, the opposite is what is practiced in the Ghanaian physics classroom at the SHSs; it appears that most teachers prefer to use the curriculum just to be informed of specific physics content to teach at each SHS level and then adopt a purely “chalk and talk” (teacher-centred) approach in teaching the content; whereby students play the role of passive observers (Buabeng & Ntow, 2010; Ottevanger et al. (2007) in Agyei, 2012:1; MOE, 2010). Apparently, the teacher-centred approach being adopted for teaching physics does not reflect what the curriculum requires, but seems to be deeply rooted in the way and manner the teachers in question have been trained. Thus, there is the need to bring to bear the nature of the teacher preparation programmes for teaching SHS science (physics) in Ghana to appreciate why certain teaching strategies are most preferred in the Ghanaian science or physics classroom. Consequently, in the discussions that follow, I examine what the teacher preparation programmes in Ghana constitute as well as its implications on the teacher trainees (pre-service teachers) in relation to their teaching practices.

### **2.2.2. Teacher preparation programmes for teaching science (physics) at the SHS in Ghana**

In Ghana, the two major universities mandated to train teachers to teach any of the science subjects among other subjects at the senior high schools are the University of Cape Coast (UCC) and the University of Education, Winneba (UEW). Both UCC and UEW offer a four-year Bachelor of Education programme to train prospective teachers for their future teaching at the SHS level. The Bachelor of Education programme with specialisation in science for example, constitutes:

- 1) Content courses, specifically—Chemistry, Biology and Physics which prepare students for their future teaching subjects.
- 2) Education courses which are in two parts—general and subject-specific ones.
- 3) Teaching practice—for which case, both UCC and UEW have a department that sees to the placement of prospective teachers in selected senior high schools off-

campus in their final year. This is aimed at developing the pre-service teachers' pedagogical skills.

There are also ICT-related educational courses that are mounted for the prospective teachers by these institutions. In UCC for example, the course entitled: Computer Application in Education has been developed as part of the general education courses. This is intended to help prospective teachers to learn of the various ways in which computers with their numerous applications could be applied in their teaching practices. Also, in UCC, most of the science content (i.e., biology, chemistry and physics) courses are taught by the School of Physical Sciences while in UEW, these courses are taken at the Faculty of Science Education. The training being rolled out by these institutions in general are all geared towards equipping prospective teachers to master their subject matters as well as develop effective teaching methodologies. This explains why for the purpose of teaching at the SHS level, the teacher training programme adopted in Ghana is structured to take a subject-training approach (Asare & Nti, 2014). Different approaches of teaching 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 (2014:5) suggested that “transmission of knowledge”; “question and answer approach”; “student-centred teaching” and others like problem solving, brainstorming among others, are the teaching methods to be adopted for training teacher trainees in Ghana. However, studies by Lewin and Stuart (2003:171) revealed that “the dominant pedagogical stance remains one where trainees are largely regarded as ‘empty vessels’ with little knowledge or experience of teaching”—suggesting that, teacher-centred approach is the main teaching approach being adopted in Ghana to train the prospective teachers to teach various subjects including the sciences at the SHSs. The tradition of Ghana as far as our education system is concerned has been described in the literature as, one that is deeply rooted in “teacher-centred exposition” (Agyei, 2012:5). 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 SHSs in Ghana. These arguments advocate potential gaps in the teacher education programmes being rolled out to train prospective teachers in Ghana—which could have serious impact on the quality of teacher education in Ghana.

Studies (Asare, 2009; Asare & Nti, 2014) in the area of education in Ghana highlighted that education quality is dependent upon the level of interactivity ascertained. Thus, to facilitate students' learning specifically at the SHS level in Ghana, the prospects of interactive teaching cannot be ignored in the teaching and learning process. Asare (2009) for instance, described interactivity as a very essential ingredient for achieving education quality. In this respect, education quality calls for interactive methods of teaching if learning outcomes are to be enhanced through interactive processes. This suggests that the teacher's role as well as the vehicular interactive instructional tool cannot be underestimated as the methods teachers apply in teaching as well as the instructional tools that they adopt in order to achieve interactivity in their classrooms are crucial for shaping knowledge and skills learners acquire at the end of the teaching and learning process (McFarlane, 2011). There is therefore a need to train teachers in ways that will advance interactive teaching and also incorporate innovative teaching methods that employ an instructional tool such as ICT.

Advancing pre-service teachers' competencies in ICT use for effective instructional process is described in literature as a complex process that requires specific strategies for successful implementation (Agyei & Voogt, 2014; Goktas, Yildirim & Yildirim, 2008; Tondeur, Aesaert, Prestridge & Consuegra, 2018). Despite the global positive perception by teacher educators about the importance of ICT uses in education, literature (e.g., Lim, Chai & Churchill, 2011) highlights gaps in the existing pre-service teacher education programmes that are adopted by teacher training institutions. This according to Haydn and Barton (2007) hinders the development of ICT-oriented competencies. Apparently, the ICT-related courses considered by most of these institutions as part of the education courses do not prepare teachers for ICT-mediated teaching and learning instructional processes (Lawless & Pellegrino, 2007). Research by Mouza et al. (2014) and Tondeur (2018) advocate different strategies for the development of pre-service teachers' competencies in the use of ICTs. Tondeur (2018:1) 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 pre-service teachers to adequately use ICT in their teaching practices. Tondeur further explained that for effective implementation of these strategies, “technology integration needs to be infused as a systemic and systematic process”. Based on this assertion, the author proposed teacher design teams (Agyei, 2012; Kafyulilo, Fisser, Pieters & Voogt, 2015; Voogt, Pieters & Handelzalts, 2016) as the needed intervention for integrating these six strategies. This seems to situate the teacher design team (referred to as Design Team approach in this thesis) as the platform by which all six strategies are put into action for the success of ICT integration. In this study, Tondeur’s proposed strategies as driven by the teacher Design Team approach were considered to be vital for coming up with a comprehensive framework (through a professional development arrangement) in order to adequately develop the pre-service teachers’ competencies in using ICTs. This was envisaged to be the needed roadmap by which the teaching and learning of physics with ICT could be enhanced to be interactive and learner-centred.

In this study, ICT was tagged as the vehicle by which the prospects of interactive teaching could be realised. The focus however, was not on ICT as a technological tool, but on how the interactive processes that ICT affords could be explored in order to track and explain how pre-teachers develop their competencies in using ICT to teach effectively. On these premises, the current study is significant for providing a research basis for shifting the current and dominant approach being adopted for training prospective teachers in Ghana to a more progressive approach that provides a unique avenue for prospective teachers to be facilitators of interactive teaching and learning process; and most importantly, make their students active-drivers of the teaching and learning process.

In the next section (2.3.), I discuss the potentials of ICT and make arguments based on reviewed literature to establish its relevance in education and then, narrow the discussion down to ICT uses in science (physics) education.

### **2.3. Potentials of ICT in education**

According to Fu (2013:112), “Information and Communication Technology (ICT) includes computers, the Internet, and electronic delivery systems such as radios, televisions, and projectors among others...”. These are technologies that are currently being used for instructional purposes. ICT is noted for its potential to provide a variety of tools for accessing information for different uses in education— as an “object”, “assisting tool”, and as “a tool for organisation and management in schools” (Jager & Lokman, 1999). Its use in these capacities is independent of the subject matter (Adedeji, 2011) and more technocentric with emphasis on learning of ICT in relation to its “functions, modes, options and communications” (Smirnov & Bogun, 2007:453). Nevertheless, there are aspects of ICT that have been designed to enhance teaching (McFarlane & Sakellariou, 2002) and hence, are highly dependent on the subject matter. For example, an ICT tool like simulations has been designed to be subject-specific for ensuring interactivity in the classroom.

Literature shows that ICT when used appropriately ascertains educational quality (Lowther, Inan, Strahl & Ross, 2008); incorporates real-life situations in the teaching and learning prospects (Weert & Tatnall, 2005); increases “access to education” (Fu, 2013:112); and provides an interactive, flexible, and convenient platform for learner-centred teaching and learning atmosphere which positions learners to be actively involved in the instructional process with expectant readiness to acquire new knowledge and skills (Castro Sánchez & Alemán, 2011; Weert & Tatnall, 2005). According to Fu (2013:112), ICT has the potential to: “assist students in accessing digital information efficiently and effectively”; “support student-centred and self-directed learning”; “produce a creative learning environment”; “promote collaborative learning in a distance-learning environment”; “offer more opportunities to develop critical (higher-order) thinking skill”; “improve teaching and learning quality”; and “support teaching by facilitating access to course content”. These remarkable benefits that ICT affords cannot be ignored for effective teaching of science. Apparently, these benefits could serve as the bridging elements for connecting science to the real world and also, very well represent the element for defining what “meaningful learning” constitutes. Consequently, the

aforementioned benefits of ICT seem to suggest a recipe for the creation of an interactive, learner-centred constructivist teaching and learning environment for effective teaching of science, and even physics to be specific. Studies in the area of ICT integration into science teaching have highlighted that ICT-based resources (e.g., simulations, videos, etc.) have potentials that allow for an alternative transmission; better explanations of various concepts in science that otherwise look very abstract; and modernity which is relevant to students (Georgiou, Dimitropoulos & Manitsaris, 2007; Donnelly, McGarr & O'Reilly, 2011). This highlights the fact that by incorporating ICT into the teaching of physics and science in general, a typical teacher-centred classroom environment (as often seen in the Ghanaian context) could be transformed into an interactive learning environment that situates learning as a process that involves active knowledge construction and not the transfer of knowledge. Thus, ICT can be said to have the capacity for improving physics education or the teaching of physics. That notwithstanding, the impact of ICT on the teaching of physics for positive results is inevitably dependent on its use in the classroom (Bransford, Brown & Cocking, 2000). This seems to suggest that teachers' roles in such an ICT revolution in education is key to realising and appreciating the affordances as well as impact of ICT as an instructional tool in education especially, as applied to physics instruction and learning. Thus, there is a need to establish a relationship between the type of ICT and the pedagogy a teacher chooses to adopt for integrating ICT in his or her teaching practices. According to Webb and Cox (2004), ICT as applied to pedagogy in educational practice goes beyond observations in the classroom to involve teachers' ideas, values, beliefs, and thinking. This is in agreement with Moseley's (1999) assertion that ICT use in educational practice is highly influenced by values and beliefs of teachers especially, when it comes to its relevance for learning. Thus, examining pedagogy in light of ICT requires a consideration of what the learning environment created by the use of ICT affords the learner as well as the teacher. ICT, when used in the classroom has a lot of implications for teachers in terms of the ICT-oriented knowledge they need to identify the appropriate resources to use and the instructional approaches to use for meaningful learning to occur (Webb & Cox, 2004). Literature highlights that "to use technology to support meaningful student learning, teachers need additional knowledge of the content they are required to teach, the

pedagogical methods that facilitate student learning, and the specific ways in which technology can support those methods” (Ertmer & Ottenbreit-Leftwich, 2010:260). This assertion by Ertmer and Ottenbreit-Leftwich seems to emphasise the complex nature of a teacher’s role when ICT is brought into the teaching and learning process. Majumdar (1997:2) elaborates these complexities by adding that the teacher’s role with ICT in the picture changes from: 1) “transmitter of knowledge to guide & facilitator of knowledge”; 2) “controller of learning to creator of learning environment”; 3) “always expert to collaborator & co-learner”; 4) “learning to use ICT to using ICT to enhance learning”; and then lastly, 5) “didactic/expository to interactive/experiential/exploratory”. These roles as highlighted by Majumdar seem to show evidence of “a paradigm shift from a teacher-centred approach to a learner-centred approach” (Scheurs & Dumbraveanu, 2014:1; Voogt, 2003) with ICT. This shift demands teachers’ ICT-oriented knowledge and pedagogical skills since the knowledge of the technology alone is not sufficient in driving an interactive learner-focused classroom with ICT (Ertmer & Ottenbreit-Leftwich, 2010).

According to Hutchison and Reinking (2011), most teachers lack the required ICT-oriented knowledge and seem to have difficulties in building on their existing pedagogical content knowledge, PCK (Shulman, 1986). Professional development arrangement has been suggested in literature (Al-Bataineh, Anderson, Teledo & Wellinski, 2008; Hew & Brush, 2006) as an effective strategy for dealing with these issues and equipping teachers with the right competencies they need in order to effectively and confidently use ICT in a way that connects to their subject matter and informs their teaching methods. In Papert’s (1987) view, such an endeavor should not be restricted to looking at the affordances and constraints of ICT and the skills needed to operate them. This suggests that such professional development programmes should among other things, be aimed at assisting teachers to develop understanding into how technology can be used to effectively change the traditional way of teaching in education. In other words, the constituents of a teacher professional development arrangement for ICT integration should not be subjected to mastering ICT skills only, but must go beyond it to explore the diverse ways of utilising ICT for the sole purpose of improving teaching and enhancing learning outcomes in order to meet the specific content needs of the learner. Thus, a teacher professional

development arrangement in relation to ICT integration is essential to teacher development in the 21<sup>st</sup> century for enabling the proposed shift from the dominant teacher-focused approach. Consequently, such arrangement should be geared towards developing teachers' competencies in ways that will help them to learn meaningfully and also, discover how the affordances of ICT could be translated into learning opportunities for students. With these ideas, the professional development arrangement considered for this study was purposed to educate and train prospective teachers on the development of ICT (simulations)-oriented teaching and learning environments and artefacts that are based on theory. I discuss the knowledge bases and the guiding principles employed in these respects later in this chapter under section 2.4.

In the next two sub sections, computer simulations and to be specific, Physics Education Technology (PhET) simulations are discussed respectively as a potential technological resource for enabling interactivity in the physics classroom at the SHS level in Ghana.

### **2.3.1. Potentials of Computer simulations**

According to Wieman, Adams, Loeblein & Perkins (2010:225), computer simulations "... can be highly effective learning tools ..., can enhance a well-designed curriculum and the efforts of a good teacher, ... and rely on the timely guidance of a teacher". These affordances seem to project the potentials of simulations for the creation of authentic instructional platforms which position the teacher as a facilitator, and stimulate learning to occur through student engagement with guidance from the teacher.

Numerous definitions have been given for computer simulations in the literature, most of which define computer simulations in different terms as computer-based models that: a) use dynamic visualisations to mimic difficult processes for observation in the real world (NRC, 2011); b) provide authentic environment to link real-life phenomena to the corresponding the fundamental science (Perkins, Adams, Dubson, Finkelstein, Reid, LeMaster & Wieman, 2004); c) provide models of real-life basis to facilitate knowledge construction by actively involving the learner (Yin, Song, Tabata, Ogata & Hwang, 2013).

All these definitions emphasise the remarkable feature of computer simulations in providing real-life environments and experiences that afford humans with the opportunity to mimic and possibly, understand complex realities of the world around us.

Many years ago, Thomas and Hooper (1991:498) described simulations in the context of education as:

*“a computer program containing a manipulable model of a real or theoretical system. The program enables the students to change the model from a given state to a specified goal state by directing it through a number of intermediate states. Thus, the program accepts commands from the user, alters the state of the model, and when appropriate, displays the new state”.*

Thomas and Hooper’s description echoes the flexible and interactive potentials of computer simulations in promoting learner-centred method of instruction in education. This supports the constructivists’ description of simulations—a virtual real-world setting presented on a computer in a way that allows students to play an authentic role as they actively engage in complex tasks that are aimed at helping them to develop higher order cognitive skills (Harper, Squires & McDougal, 2000; Sahin, 2006).

Computer simulations have been mostly used in the past, and even now for the teaching of science in ways that appear to emphasise the constructive perspective about using simulations. In science classrooms all over the world, computer simulations have been of interest to researchers for over 20 years with findings that have been described to be 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; providing tools that promote scientific inquiry (Dwyer & Lopez, 2001); and enabling conceptual change (Finkelstein et al., 2005; Stieff, 2003; Zacharia & Anderson, 2003; Zacharia, 2007). Its potential for distance education (Lara & Alfonseca, 2001) as well as “simulating labs that are impractical, expensive, impossible or too dangerous to run” (Sahin, 2006:1) are also noted in literature. The benefits of computer simulations as indicated by these authors reflect the key elements of constructivism and advocate a type of teaching approach that is defined as a “purposeful-

inquiry” (Hofstein & Lunetta, 2003); where learning ceases to be the sole responsibility of teachers; instead, defines the learning as a highly student-oriented process. According to Esquembre (2001), simulations are the “most extended and studied categories of instructional software used in physics education”. Consequently, the potentials of simulations in the physics classroom have been explored and studied in different contexts in relation to different physics concepts in literature (Jimoyiannis & Kosmis, 2001; Dega, Kriek & Mogese, 2013). For example, Jimoyiannis and Kosmis (2001) used computer simulations to foster students’ understanding of physics concepts such as velocity and acceleration in projectile motion. Findings of their work, as explained in Esquembre (2001) showed that by the use of simulations, students were provided with the conducive environment to: a) “develop their understanding about the phenomena and physical laws through a process of hypothesis-making and idea-testing”; b) “... develop an understanding of the relationships between physical concepts, variables and phenomena”; C) “employ a variety of representations (images, animations, graphs, numerical data) that are helpful in understanding the underlying concepts, relations and processes”; and d) “investigate phenomena that would not be possible to experience in a classroom or laboratory” (Jimoyiannis & Kosmis (2001) in Esquembre , 2001:4). All these elements seem to illustrate the affordances of computer simulations in promoting constructivism in the classroom where students are stimulated to construct their knowledge on the subject matter being studied based on their experiences with simulations; which eventually, according to authors, helped the students to get better understanding of the physics concept and hence, obtained higher scores in the tasks given them (Jimoyiannis & Kosmis, 2001). Trundle and Bell (2005) compared students’ conceptual understanding before and after an instruction on lunar concepts mediated by planetarium simulations. Their findings showed that the affordances of simulations (i.e., in making more observations, allowing predictions to be explored, taking consistent and accurate measurements) were essential to the enhancements in students’ understanding of the lunar concept as it allowed them to observe the moon phases which in reality, seemed impossible to observe. This brings out the potential of simulations as a visualising tool as rightly noted by Kohnle (2014) in that, with simulations, students are able to visualise invisible abstract concepts as well as observe microscopic processes.

Furthermore, computer simulations have been used to examine gains in students' conceptual understanding of electricity and magnetism (Dega, Kriek & Mogese, 2013). Dega et al. (2013) revealed that additional instructional support with simulations is necessary for improvement in students' understanding of physics. Other 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, 2010). These examples seem to project interactive simulations as a very useful tool for effective teaching of physics as well as the development of conceptual understanding.

Literature shows that the effectiveness of simulations when used for instructional purposes is 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 simulations-based activities with the intended curriculum (Bell & Smetana, 2008). According to Bell and Smetana, the effectiveness of simulations in a science classroom can be limited by the method of application and to some extent, integration into teaching. Consequently, teachers have a very crucial part in this respect as their means of integrating simulations into their teaching practices may vary and may go a long way to influence the learning outcome. Inevitably, instructional strategies with simulations must be carefully chosen to support meaningful learning of science (physics to be specific) for its potentials to be realised effectively. Bell and Smetana (2008) further emphasised that for effective use of simulations that promote meaningful learning, computer simulations must be used in the science classroom to:

- supplement other instructional strategies, and not to replace.
- facilitate student-centred mode of instruction.
- highlight the limitations or weaknesses in the simulations employed.
- bring the content into focus not the technology (simulations).

These guidelines seem to give insights into the kind of pedagogical approach to adopt with simulations. In Sahin's (2006) view, the pedagogical approach in this respect could be either instructive or constructive. The author further explained based on literature that,

instructive use of simulations focuses on informing, reinforcing, and experimenting. However, if simulations are employed for instruction with the elements of interest being experiencing, integrating and conceptual change, then that constitutes a constructive way of using simulations. Other methods mentioned in literature include simulations' use in the science classroom to allow for prediction, observation, exploration, analysis, verification, and explanation (Pol, Harskamp & Suhre, 2005; Whitelock, Scanlon, Taylor & O'Shea, 1995) among others. With these teaching methods, it appears, the pedagogical approach for the integration of simulations into teaching practices could be dependent on the teachers' preferences which might be subjected to: 1) the complexities in the subject/content, 2) learning goals, and 3) the availability and accessibility of resources (e.g., computers and computer simulations software). In addition, the context in which the teaching and learning processes is to be situated should also be taken into consideration. Apparently, the strategies to adopt in using simulations for teaching science might not be as easy as it seems (Baggott La Velle, McFarlane & Brawn, 2003). In Baggott La Velle et al.'s (2003) view, it would require careful planning and critical decisions on the part of a teacher to use simulations effectively and to secure the learning outcomes anticipated. Their assertion seems to highlight the need for well-grounded framework(s) to systematically guide teachers to develop competencies that could inform and shape their teaching practices with ICT in a manner that ascertains interactivity in the science (physics) classroom.

Research work conducted in relation to interactive teaching of physics and science in general with simulations as an ICT tool or as the vehicle for implementing the change process have used and proposed different frameworks as a conceptual basis to ground their work on interactive teaching. For example, a study by Rehn, Moore, Podolefsky and Finkelstein (2013) proposed a framework for using interactive simulations in an educational setting positing that three elements—the Simulation, the Assignment, and the Environment influence how students use the simulation. Kaheru and Kriek (2011) also examined the use of interactive computer simulations as a means for improving the ways and manner in which physical science is taught based on two theoretical frameworks—*Cognitive Load theory* which supports interactivity on the basis that the way information

is presented to a learner as well as the learning task given to a learner to explore can enforce their active mindedness (Paas, Renkl & Sweller, 2003); and the Multimedia Theory of learning which advocates that learning as a process is not without participation and active interaction (Mayer & Chandler, 2001). Furthermore, de Jong (2010:449) highlighted the fact that learning with simulations have been considered as “involving an inquiry cycle consisting of processes such as hypothesis generation, experiment design, data interpretation, and reflection”. Though all these frameworks highlight different theoretical grounds to incorporate simulations as an ICT tool for effective learning taking into consideration the learners’ need, a very important element; the teacher, is not mentioned. It is therefore not clear what the teacher’s role would be, neither are the means by which teachers could take up teaching with simulations under the umbrella of these frameworks articulated. Rehn et al. (2013) for instance, agreed that the teacher is an important resource, however, in their proposed framework, the teacher element was not considered even though, they made mention that the teacher could be the element to control the whole learning process informed by the framework or even interact with each of the three elements as in the framework. The complexity of such a proposition is also not clear as the framework does not make provision for direct strategies for integrating the elements (simulations, assignment and environment) in the framework. This informed the present study about the choice of framework (see section 2.5) to adopt. The teacher in this context is considered as a key resource for achieving interactivity in the physics classroom with ICT (simulations) at the SHS level. In this regard, the teacher requires a specific type of knowledge to drive the interactive instructional process that ICT affords.

A number of simulation software have been developed to promote effective teaching of physics at the high school level. However, in this study PhET simulations were employed as the ICT tool for enabling interactivity in the Ghanaian SHS physics classroom. Thus, in the next subsection, PhET simulations are discussed extensively to establish its appropriateness for the current study in relation to its potentials. Also, how it fits into the Ghanaian context is explained.

### **2.3.2. Physics Education Technology (PhET) simulations for interactive teaching of high school physics**

In this study, PhET simulations were classified under targeted simulations (Clark, Nelson, Sengupta & D'Angelo, 2009) on the basis that, they are "... stand-alone simulations designed to cover a particular topic in a scientific discipline" (Rehn et al., 2013). In this context, the scientific discipline was physics. PhET is a suite of interactive computer simulations (Finkelstein, Adams, Keller, Perkins & PhET Project Team, 2006) developed on research basis at the University of Colorado, Boulder to enhance the teaching and learning of not only physics, but in recent times, mathematics and other sciences like biology and chemistry (<http://phet.colorado.edu>). The PhETs are designed to provide an interactive platform that engages students to learn through exploration and discovery with the goal to help students to connect real-life phenomena to the underlying subject matter in a particular science (Finkelstein et al., 2006). According to Perkins et al. (2004), the simulations were originally designed to "support student engagement with and understanding of physics concepts". Apparently, this may be the reason why the original acronym "PhET", for "Physics Education Technology" still remains to date even though, the PhET website has been upgraded to include other fields of study in the sciences as well as mathematics. With a purpose to introduce students to new and interactive ways of studying physics, PhET could be described in my own words, as the "possible for the impossible" when it comes to physics— meaning, it could very well be a substitute for the abstract concepts in physics that cannot be visualised in the real-world (e.g., the properties of gases and the atomic structure) or it could be taken as a substitute for the sophisticated operational physics laboratory usually envisioned by educational stakeholders—which seems normally difficult to establish due to financial constraints that come with it; especially, in the African context. Furthermore, among the sciences, PhET is a popular ICT instructional tool due to the fact that it is free— users need not pay any amount to enjoy its use. It is a java-based animation with a remarkable feature that allows users to run online, download from the website and use offline. Thus, it is not limited to internet access. Consequently, these are the features of the PhET simulations that informed me in using it as the interactive ICT tool for the current study. Essentially, it served as a convenient ICT tool for teaching physics in the Ghanaian context.

Finkelstein et al. (2006) mentioned (in their article which describes PhET simulations as “High-tech tools for teaching physics...”) six characteristic features of PhET simulations based on their own assessment of the simulations as well as literature on PhET uses. These include: a) an engagement and interactive approach with the aim to provide an interactive interface that allows room for a user to explore, interact, manipulate or even change some parameters to achieve their learning goals—thus, promoting student engagement as noted by Redish (2003); b) dynamic feedback intended to provide direct feedback to students as they interact with the simulation environment—according to Clark and Mayer (2003) such a feature is essential to developing students’ conceptual understanding and the relationships that exist among the concepts under exploration; c) constructive approach which is peculiar to building on students’ prior knowledge. This however, involves some level of guidance or support for effective learning outcomes as explained by Finkelstein and co-workers; d) workspace for play and tinkering which according to the authors (Finkelstein et al., 2006:2), involves learning by means of “systematic play”, “messing about” as well as “open-ended investigations”; e) visual access to conceptual physical model which is purposed for students to visualise features of microscopic and abstract physics systems like electrons, photons, electric field, gas molecules etc. that are difficult to observe with the naked eye in reality; and then lastly, f) productive constraints for students which is featured to keep the students focused on specific tasks with the simulations as well as develop their understanding of key concepts through a gradual process. Perkins et al. (2004:2) throw more light on the sixth characteristic feature mentioned by Finkelstein et al. (2006) stating that PhETs are more effective when learners are “constrained to be effective”. They further explained that this could be achieved by way of guidance and could be realised either through the teacher in a lecture or by “use of guided activity in homework or lab”. Thus, the emphasis is on providing some level of guidance for students to be productive in ways that motivate them to achieve their learning goals. The question that arises at this point with regards to the sixth feature (mentioned earlier) would be: “What level(s) of guidance are needed with the PhETs for effective teaching?”. This seems to be the question Adams, Paulson and Wieman (2008) sought to answer in their article entitled: “What levels of guidance promote engaged exploration with interactive simulations?” In this article, four different

levels of guidance (no instruction/guidance—Type A, driving questions—Type B, gently guided—Type C, strongly guided—D) were defined and compared. The interactive simulations discussed was the PhETs. The study revealed through student interviews with simulations that, the levels of guidance that facilitate engaged exploration of the PhETs were the types conditioned with either no guidance/instruction or with driving questions. According to the authors, these two levels, Types A and B required students to play with the simulations and talk about the things they do loudly as they explored the simulation and required students to explore the simulations using only guiding questions respectively. Their findings also showed that with these two types of guidance, students gained deeper understanding into the phenomena under study and were able to develop a mental framework as they explored the simulation through their own questioning. With these findings, it can be said that PhET simulations when used for instruction with no guidance or minimal guidance, encourage innovation on the part of students and equips students (Adams et al., 2008) to be constructive in ways that prepare them to learn by themselves. Irrespective of the advantages as mentioned by Adams et al. in relation to the Type A and B levels of guidance, it appears the Type B is the most effective for realising meaningful learning as well as interactivity with most of the PhET owing to the authors' assertion that "minimal but nonzero guidance with many of the PhET simulations promotes optimum engaged exploration and learning" (Adams et al., 2008:1). Their statement in this regard seems to hint that the authors consider the level of guidance that is conditioned with only guiding questions (i.e., Type B) to mean minimal guidance.

Finkelstein et al.'s (2006) features of PhET simulations greatly informed the choice of theoretical underpinnings considered for the study. In particular, these features of the PhET simulations identified and explained by Finkelstein et al. were classified in this study to constitute some of the elements that were defined to characterise interactivity that ICT (simulations) affords in the physics classroom. Consequently, linking these remarkable features to Howland et al.'s (2012) "Five dimensions for meaningful learning with ICT" (in Koh, 2013) seemed appropriate for the study even though, the *Cooperative* dimension (Howland et al., 2012) appears submerged among the six features that Finkelstein et al., propose. Apparently, the *Cooperative* dimension appears to be more pedagogy-related. This leaves room for further investigations that could bring out explicitly, what

characteristic feature of the PhET could best fit the *Cooperative* dimension posited by Howland et al. (2012) in order to bring about improvement in teaching as well as enhanced learning outcomes. How the PhET simulations could be adapted into physics instruction was one of the foci considered for this study. In addition, as the current study sought to promote interactivity in the physics classroom, providing an explanation or understanding of how the PhET simulations employed in the study projected each of the five dimensions including the cooperative aspect was crucial for the formation of design principles or the development of theory.

Literature discussed in this particular subsection (2.3.2) so far, has brought to focus the affordances of PhET simulations and the possible diverse ways the tool could be adopted for the teaching of high school physics. More explicitly, the literature discussed to this point seems to suggest that if the PhET simulations are to be considered or employed as a technological/ICT tool to facilitate student-oriented instructional prospects for the teaching of physics or science in general at the high school level (but not restricted to it), then the pedagogy to adopt cannot be ignored as it forms part of the core ingredients (“content”, “pedagogy” and “technology”) for every “good teaching” that Mishra and Koehler (2006) second. Hence, how ICT changes the teacher’s role in the classroom is reiterated.

### **2.3.3. Barriers to ICT implementation in education**

Earlier discussions highlighted several potentials of ICT in education especially in making the teaching of physics and science as a whole, interactive, learner-centred. Despite the emphasis made with respect to ICT’s potential for changing the role of the teacher in the classroom, ICT integration as applied to its use for effective teaching is not without hindrances. According to Donnelly, McGarr and O’Reilly (2011) there are a lot of barriers to overcome for a successful integration of ICT especially, at the post-primary school level of education. Literature highlights different categories in relation to the factors that inhibit teachers from taking up ICT in the classroom. Ertmer (1999) for example, described a simple model that constitutes two types of barriers in this regard; a) first order barriers

which can be resolved by the provision of money and b) second order barriers which Ertmer explains to be deeply tied to teachers' core beliefs. Snoeyink and Ertmer (2001), as stated in Khan, Hasan and Clement (2012:67&68) further expanded on Ertmer's first order barriers to include "lack of equipment, unreliability of equipment, lack of technical support and other resource related issues". Among all the factors highlighted by Snoeyink and Ertmer (2001), lack of equipment (mostly referred to as lack of ICT resource or infrastructure) has been identified in literature (Agyei, 2012; Donnelly et al., 2011; Khan, Hasan & Clement, 2012) as one of the greatest barriers to ICT integration in the classroom.

Zhao, Pugh, Sheldon and Byers (2002) categorised barriers to technology (ICT) integration into three interactive domains; teacher domain, innovative domain, and context domain with a lot of emphasis on the teacher domain in that; it encompasses teacher-biased elements such as technology proficiency, pedagogical compatibility, and social awareness. These seem to echo the important role teachers play in any ICT integration initiative in education. Groff and Mouza (2008) further brought to light (based on literature examined) six critical factors that influence the success of technology integration. These according to the authors included:

1. *Legislative factors*: which entail "... lack of research on the efficacy of technology-based instruction and legislative policy that shifts frequently or is innately designed to facilitate the introduction of technology in the classroom" (Groff & Mouza, 2008:26). This definition seems to suggest that the teacher has no control over the legislative factors as barriers and thus, cannot claim any sense of ownership to that effect.
2. *District/school-level factors*: Authors describe this to constitute "community members and administrators who may push for instructional practices that do not fall in line with research-proven methods and the school environment which may be lacking adequate access to technological and human resources" (Groff & Mouza, 2008:29). This aligns with Ertmer's first order barrier as it can be addressed financially.
3. *Teacher factor*: This involves "teacher characteristics such as lack of technology-based skills, attitudes and beliefs that do not favor technology-based learning, concerns towards the introduction of computers, and lack of familiarity with support

resources that can prove to be barriers to technology integration in the classroom” (Groff & Mouza, 2008:31). Interestingly, all these factors as mentioned by the authors could be classified under Ertmer’s first order barriers. Hew and Brush’s (2007) explained the lack of technology-based skills factor as one of the main reasons why teachers shy away from using technology as most of them seem to have gaps in their knowledge where ICT is concerned. The issue of teachers’ attitudes is also affirmed in light of Mumtaz’s (2000) study which revealed that teachers’ attitudes can prevent them from using ICT. This however seems to be specific to the case where the teacher’s attitude towards ICT is negative as observed in the late 90’s by Moseley and Higgins (1999) that a teacher’s attitude if negative, could serve as a barrier to the integrating process. Beliefs as a barrier can be explained based on how they are brought into action through practice (Donnelly et al., 2011). These highlights are clear indications that the teacher factor is pedagogical in nature as teachers seem to lack the necessary knowledge and skills that are ICT-related for their uptake of ICT as an instructional tool and thus, pose as a major challenge to success of any ICT initiative and implementation process if underestimated and not attended to with agency.

4. *Factors associated with the technology-enhanced project*: In the authors’ view, these are factors that are innovation-oriented and “can inherently possess barriers to achieving success if it exhibits distance from the school context and dependence on resources outside of the teacher’s control” (Groff & Mouza, 2008: 32). In Zhao et al.’s (2002) view, these two characteristics of technology-based project are crucial as they have the tendency to greatly influence the possibilities for success. These barriers as mentioned herein seem to caution the need to contextualise technology-enhanced projects so that it does not become isolated from the existing instructional context (i.e., the school’s culture, value set, teacher current practices and prior experiences, existing technologies in the school) as well as available and accessible school resources (Zhao et al., 2002).
5. *Student factors* (i.e., factors associated with students): This type of barriers was included by authors on the grounds that students are the “primary operators” of “technology innovation” and hence, describe barriers to include factors such as “limited prior experiences with technology-based projects, technology skills, and

attitudes and beliefs toward computers” (Groff & Mouza, 2008: 34). This suggests that the learner’s satisfaction with technology innovation in terms of how it is used in the classroom cannot be ignored as it goes a long way to influence the implementation process.

6. *Factors inherent to technology itself*: This was explained by the authors (Groff & Mouza, 2008) to mean that “by its very nature, technology brings its own challenges and therefore, creates its own barriers to success in the classroom”. Some of the challenges encountered according to the authors included “hard drive failures, insufficient memory, computer systems incompatibility with peripherals and software, misplaced, lost or corrupted files” etc. (Groff & Mouza, 2008: 34).

Inasmuch as all six factors are deemed critical and important, Groff and colleague pin point to the fact that it is not all the factors that teachers have control over. In the author’s view, barriers that are legislative related as well as those that are inherent to technology itself cannot be easily manipulated, directly influenced or altered by individual teachers. This suggests that these types of barriers cannot in any way be resolved by individual teachers and thus, can be taken to be outside the teacher’s domain.

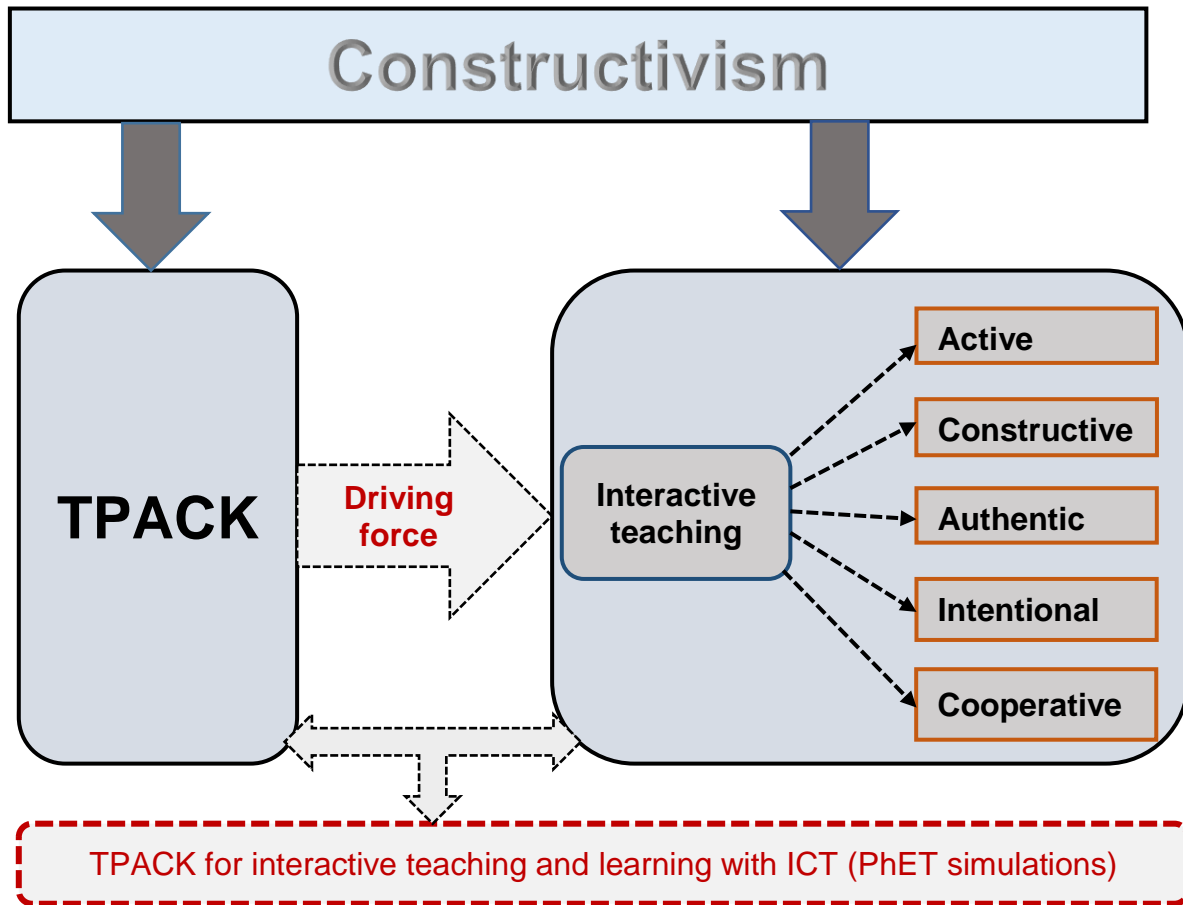
Limited time has also been identified in literature (Güzel, 2011; Jimoyiannis, 2008; Pelgrum & Plomp, 1991) as one of the principal obstacles to technology implementation process. Jimoyiannis (2008) for instance, classified time constraints under technical factors that dishearten technology use in the classroom. Pelgrum and Plomp (1991) also identified inadequate preparation time for the development of computer supported lessons as one of the pressing and occurring factors impeding teachers’ willingness to incorporate technology in instruction. Güzel (2011) revealed time as one of the major barriers to the success of computer supported physics classes. In particular, the study revealed that almost all the participants that were interviewed in the study expressed their concerns about not being able to cover the content of syllabus within the allocated time frame as expected. These literatures herein seem to suggest that ICT when involved in the instructional process usually affects prior lesson preparation as well as the lesson delivery time and thus, does not motivate teachers to want to use technology in the classroom for the fear of not being able to complete the allocated contents they are to

cover within stipulated period of time. The consequence of such inhibition with time especially, in the Ghanaian context is the tendency for teachers to “reinforce the phenomenon” of “teaching to the test” (Agyei, 2012:40). According to Agyei, this phenomenon instigates teachers to cover topics in a rush with the intent to complete the syllabus in time for examinations without any consideration for meaningful student learning. This suggests that when time becomes a limitation in the ICT integration process “quantity” is given preference over “quality” on the part of teachers and hence, makes the change sought with ICT in the educational picture limited.

#### **2.4. Theoretical/conceptual framework underpinning the study**

Constructivism was adopted as the overarching theory underpinning the present study. Specifically, constructivism was conceptualised as the underlying approach for bringing to bear interactive teaching with ICT (simulations) in the physics classroom at the senior high school level of education. Thus, by making constructivism the overarching theory, pre-service teachers’ experience in developing ICT-based activities and implementing it in a constructivist manner was explored. In this regard, the study combined two theories: technological pedagogical and content knowledge (TPACK) by Mishra and Koehler (2006) and the “five dimensions for meaningful learning with ICT” by Howland et al. (2012) as adapted by Koh (2013). In the context of this study, TPACK was used on the basis that teachers need some kind of ICT-oriented knowledge to ensure interactive teaching and learning of physics with simulations at the SHSs. Hence, TPACK was conceptualised as the knowledge that teachers need to drive interactive prospects with ICT (simulations) and design simulations-supported lesson materials for physics. The five dimensions for meaningful learning with ICT (denoted by 5DML-ICT in this thesis) framework, (as adapted by Koh (2013)) was therefore used as a lens to characterise and define interactive teaching and learning of physics with ICT (simulations). These theories as contextualised herein, constituted the conceptual framework that grounded the current study and thus, provided the fundamental insights for tracking and understanding pre-service teachers’ TPACK for interactive teaching and learning with ICT (simulations). Figure 2.1, illustrates how these theories were conceptualised in the context of the study.

In the subsections that follow, each of the aforementioned theories in the proposed conceptual framework is discussed broadly in light of literature to establish its relevance for the study. In addition, how each was operationalised is also discussed.



**Figure 2.1: Proposed conceptual framework for study.**

#### **2.4.1. Constructivism**

Jones and Brader-Araje (2002) defined constructivism as an educational theory that has had a major impact on educational practices in recent years because of how teachers have taken it in as a pedagogical approach. Other researchers (e.g., Voogt, 2003) have described it as a vehicle for shifting the teacher-dominated traditional classroom to a learner-dominated classroom. Hence, constructivism represents a way of knowing. Constructivism therefore positions learners as the focus of the instructional process with their previous knowledge and experiences serving as the building block for the construction of new knowledge (Mikre, 2011). Also, teachers cease to be the “transmitters of knowledge to guides” (Majumdar, 1997:2) in their classrooms. By this, both teachers and learners will be motivated to be actively engaged for learning to take place in an

atmosphere that is highly driven by interactions, reflections, and personally experiences. The emphasis is on meanings that learners construct for themselves. Seemingly, constructivism when applied, changes the teacher's role in the classroom. The role of the teacher is shifted to embrace a constructivist-oriented way of teaching with the learner as the central point in the instructional process. Constructivism as a learning theory influences not only how learning occurs, but also the way of teaching. However, it is the environment in which constructivism is situated for learning that informs the teaching strategy employed.

Literature discussed so far highlights in different words that a constructivist learning environment is among others, activity-oriented; student-centred; real-world linked; goal-oriented and highly collaborative. The latter element seems to project Vygotsky's (1978) constructivism which emphasises the importance of the social context in learning. Vygotsky also advocated a collaborative dimension to the teaching as a way of championing social interactions in the classroom. This suggests that constructivism involves not only the teacher as a guide, but seeks to provoke students to help each other in order to foster their understanding of concepts that under normal circumstances, they would not understand on their own. If these features as mentioned in literature are to be considered then, designing and creating a constructivist environment that is socially-inclined is a difficult and complex task which would require a teaching strategy that aligns with constructivists' ideas, some level of guidance as well as rich resources and tools to facilitate the instructional process effectively (Lourdusamy, Koon & Khine, 2001). These factors seem to be teacher-related and thus, position teachers' role in the constructivist classroom to be relevant.

Literature positions ICT as a rich catalytic resource for enabling constructivist learning in education (Volman, 2005). When used together with a constructivist teaching approach, ICT has the potential to yield positive learning outcomes (Brush & Saye, 2000). This could be linked to ICT's remarkable potentials for the creation of an authentic, collaborative, and student-centred learning environment which seem to be highly grounded in the constructivist's idea of inquiry learning. This suggests that ICT in a constructivist teaching

and learning environment provides a progressive platform for knowledge construction through guided inquiry; with the learner taking full control of the learning wheel. Teachers aiming to incorporate these constructivist ideas using ICT would therefore, require: 1) a certain type of knowledge and skills to drive their teaching practices effectively in this direction; 2) an ICT-oriented teaching strategy that is constructivist-based; and 3) an understanding of the characteristics that informs the pedagogical approach under the constructivist educational umbrella. These are the ideas that informed my selection of constructivism as the overarching theory underpinning this study.

In this research, the pedagogical strategy employed (for training the participants of the study) was purely constructive and was defined purposely to reflect interactivity in the Ghanaian SHS physics classrooms. Interactivity was characterised by use of the 5DML-ICT model (as adapted by Koh, 2013). Also, the constructive way of using simulations for instruction was highly emphasised in this study as the theoretical grounds based on which interactive teaching and meaningful learning could be realised. The interactive teaching prospects were conceptualised in this study to be driven by the TPACK framework on the basis that TPACK is the specific ICT-oriented knowledge that teachers require in order to enforce interactive teaching in a constructivist classroom.

In the next subsection, I discuss the TPACK framework to establish its relevance for the study.

#### **2.4.2. Technological pedagogical and content knowledge (TPACK) framework**

Mishra and Koehler (2006) noted that the development of theory brings into educational technology as well as the prospects of teaching as involved in teacher education, an added level of a complexity that is characterised by many types of knowledge. They further explained that embedded in the complexities of teacher knowledge are certain fundamental components that apart from what each one of them brings to the forefront of educational technology, present a complex interaction or relationship among themselves

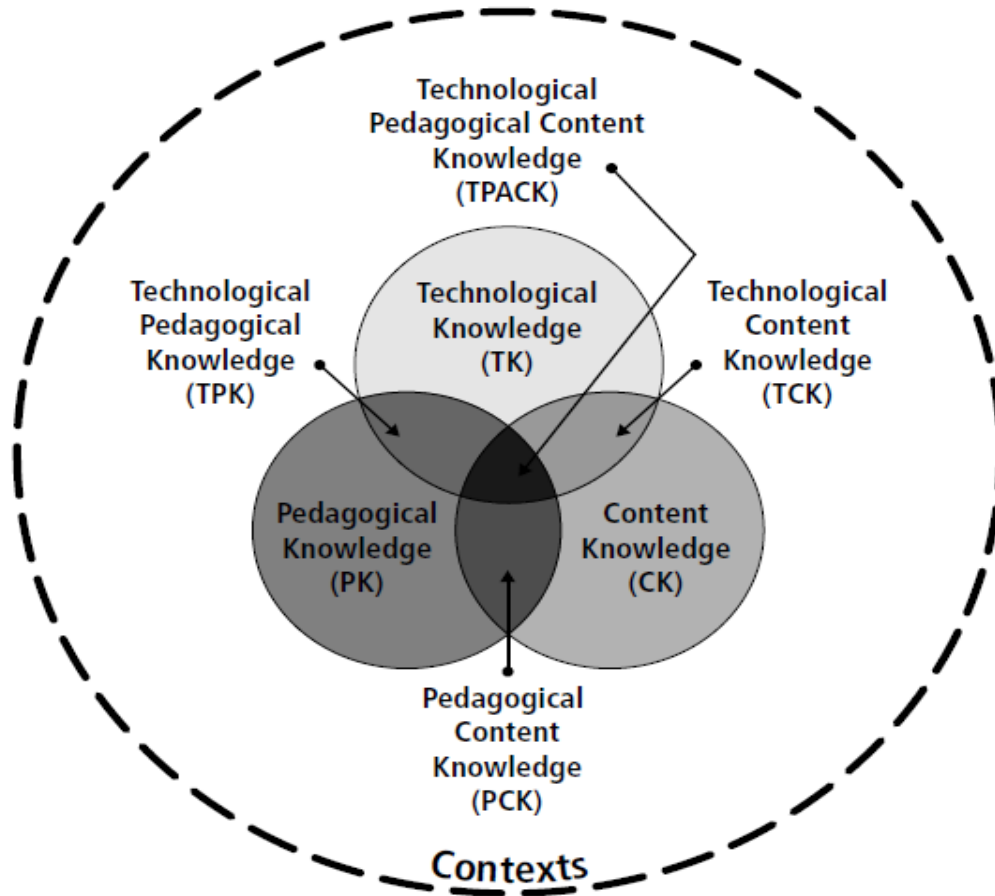
in a way that grants teachers the opportunity to develop ICT-oriented competencies. Based on this, the authors proposed that pedagogy, content and technology are the three core components of a good teaching. The framework “Technological pedagogical and content knowledge (TPACK)” stems from Shulman’s (1986) model on the required knowledge bases for teacher education which was articulated as pedagogical content knowledge (PCK) on the grounds that most teacher education programmes historically and even now, consider pedagogical knowledge (PK) and content knowledge (CK) in isolation from each other. According to Shulman, the aspect usually overlooked in this regard is the interplay between pedagogy and content knowledge. Shulman defined Pedagogical Content Knowledge (PCK) as the way and manner a particular content should be taught taking into consideration strategies to interpret the subject matter as well as the selection of the appropriate means to present the content in ways that are both comprehensive and accessible to learners. In different words, PCK recognises that teachers need three key ingredients to be effective in the classroom: 1) “...the essential facts and skills of the subject they teach”; 2) “... the skills and strategies that help students learn”; and 3) “the ability to select appropriate pedagogical strategies to teach their content to the specific audience for the lesson” (Colvin & Tomayko, 2015:69). From Mishra and Koehler’s (2006) perspective, a successful teacher in the classroom is one who has the capacity and ability to draw from pedagogy, content and technology to establish a relationship between them. The relationship between these three knowledge domains is what they termed as “Technological Pedagogical and Content knowledge (TPACK)” which builds on Shulman’s PCK framework to include a “T” component (i.e., Technology), and thus, gives birth to the technological knowledge (TK) that Mishra and Koehler articulated. The TPACK framework therefore adds a third component to the knowledge bases and three new interrelated knowledge domains to Shulman’s PCK. Literature shows that of immense importance is the way in which the three core components are used together for effective teaching in a manner that helps students to learn the content (Koehler, Mishra & Cain, 2013; Neiss, 2005).

In the paragraphs that follow, the TPACK framework is discussed to establish its relevance for the present study. Furthermore, how the TPACK framework is adapted in this research is also discussed and elaborated.

Several studies (Chai, Koh & Tsai, 2013; Prabawa, 2017; Voogt & Mckenney, 2016) in literature highlight the importance of TPACK in relation to technology integration in teacher education. Chai et al. (2013:31) described TPACK as an important framework when the focus is “to guide research in teachers’ use of ICT”. Prabawa (2017) recommended that TPACK is the starting point when technology is to be envisioned “as an integral partner for education”. In their view, TPACK does not only impact the teacher’s mastery of subject matter (content), but has the potential for developing in the teacher, the required skills to incorporate ICT into their teaching practices. Voogt and McKenney (2016) and Fisser, Voogt, van Braak and Tondeur (2015) described TPACK as a conceptual framework/base to consider in order to gain valuable insights into the kind of knowledge teachers need to integrate technology in their teaching practices. These views, as explained by the aforementioned authors, situate TPACK as a major driving force for effective technology integration. Therefore, the teacher as the agent of change (Fisher & Mahajan, 2006) has a crucial role to play for the success of technology innovation that is purposed to yield positive outcomes. Findings of the study by Ertmer and Ottenbreit-Leftwich (2010:260) clearly espoused this stance that “for meaningful student outcome with technology, teachers need knowledge of the technology itself, knowledge of the content required to teach, the pedagogical methods that facilitate student learning, and the specific ways in which technology can support those methods”. This seems to suggest that TPACK is essential for attaining success with ICT use in the classroom.

TPACK consists of seven different knowledge domains (see Figure 2.2): 1) Technology knowledge (TK), 2) pedagogical knowledge, 3) Content knowledge, 4) Technological pedagogical knowledge (TPK), 5) Technological content knowledge (TCK), 6) Pedagogical content knowledge (PCK) and 7) Technological, Pedagogical and content knowledge (TPACK) (Koehler et al., 2013). TK, PK and CK represent the three major components of teachers’ knowledge. TPK, TCK, PCK and TPACK represent the various

interaction that exist between and among the major components of the TPACK model (Koehler et al., 2013). Thus, the TPACK framework was developed taking in to consideration: a) each of the three knowledge domains in isolation (TK, PK and CK), pairs of the main knowledge domains (TPK, TCK and PCK), and then finally, a triad (TPACK). This is illustrated in Figure 2.2. In Figure 2.2, TK, PK, and CK have been illustrated with three circles with the intersections of two of these three circles representing TPK, TCK and PCK. The middle section is where we have all three circles intersecting and thus, forming the triad, TPACK as mentioned earlier. According to Chai et al. (2013), TK, PK and CK are “knowledge about how to use ICT hardware and software and associated peripherals”, “knowledge about students learning, instructional strategies, different educational theories and assessment methods”, and “knowledge of subject matter” respectively. TCK refers to knowledge about the different ways in which “... technology and content are reciprocally related” (Mishra & Koehler, 2006:1028). This definition by the authors seems to suggest that TCK domain could either be technology-driven whereby the affordances of technology influence the subject matter in realising TCK or content-driven; whereby, adequate content on the part of the teachers influences the way and manner technology is used in representing the content. TPK is the knowledge a teacher has about the potentials as well as constraints of technology in providing a platform for different teaching strategies (Koehler & Mishra, 2008).



**Figure 2.2: The TPACK model (Koehler, Mishra & Cain, 2013).**

PCK is referred to as the knowledge a teacher requires in order to develop and enact an effective instruction that is content-driven (Shinas, Yilmaz-Ozden, Mouza, Karchmer-Klein & Glutting, 2013). The last domain, TPACK refers to the unique body of knowledge that is highly dependent on a teacher’s understanding of how the interplay between TK, PK and CK can be realised and applied for the development of an effective technology-integrated lessons (Agyei & Voogt, 2012; Harris et al., 2009). This definition highlights the transformative perspective of the TPACK model. According to Chai, Koh and Tsai (2010), there are two viewpoints when it comes to the epistemological nature of the 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) and thus, recognises TPACK as a unique body of knowledge (Harris et al., 2009). The second viewpoint is the integrative model which does not recognise 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 key to the realisation of the interconnections that exist between the three knowledge domains.

In this study, the TPACK framework was considered more suitable for exploring the pre-service teachers' competencies in using ICT for effective teaching of high school physics mediated by simulations as the technological tool. The focus here was to track and understand how the pre-service teachers' TPACK could be developed and applied through a professional development arrangement. In addition, how the combined effect of three knowledge domains (i.e., TK, PK, and CK) unfolded in the microteaching sessions as prescribed in this study was key to explaining how teaching improved and learning enhanced with ICT. Thus, I do not take any stand with regards to the two viewpoints about the TPACK framework, but consider each description relevant for achieving the objectives set for the present study. In this study, attention was given to knowledge domains in which technology is involved (i.e., TK, TPK, TCK and TPACK) (see Figure 2.3).

As indicated in Figure 2.2, the TPACK framework lays much emphasis on the "context". This was the later addition to the TPACK model in 2008 by authors on the grounds that "teaching with technology does not take place in isolation, but is each time situated in a specific educational context" (Fisser, Voogt, van Braak & Jo Tondeur, 2015:3). Literature (George, 2014; Rosenberg & Koehler, 2014) highlight that "context" is the part of the 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 realisation stage. Kelly (2008:5257) defined context as the "fourth area of knowledge teachers must incorporate into tier TPACK based instructional designs if they are to be effective ...".

According to Kelly, context encompasses many things: “the physical features of the classroom; the demographic characteristics of students and teachers; the cognitive, experiential, physical, social and psychological characteristics of students and teacher, and teacher knowledge, skills and dispositions” (Kelly, 2008:5257). In Koehler, Shin and Mishra (2012) view, it is the synergetic effect of these elements which ensures uniqueness of the grounds on which the TPACK model is adapted. This seems to imply that TPACK as a framework goes beyond considering the three knowledge domains in isolation and emphasising 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.

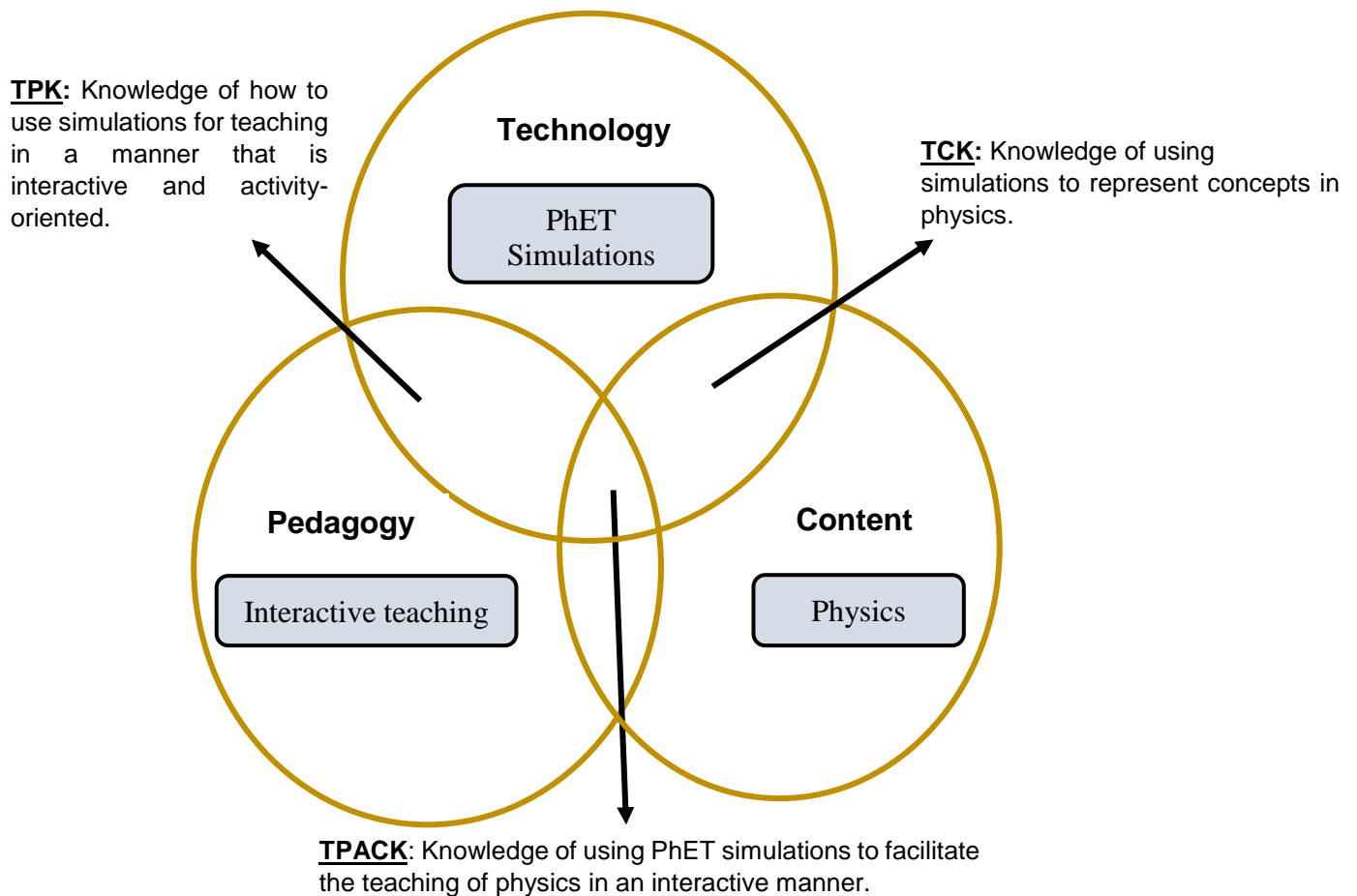
Though the TPACK framework, as shown in Figure 2.2 has been recognised by educational researchers for its potential in technology integration in education, it is not without constraints. The TPACK framework has been criticised on different issues in literature. It has been criticised among others for possessing: 1) too many knowledge domains which make it difficult to distinguish or separate them from one another (Archambault & Barnett, 2010; Brantley-Dias & Ertmer, 2013); and 2) unclear boundaries (Cox & Graham, 2009) which does not give clear definitions for its elements or make distinctions between them (Graham, 2011). Furthermore, Graham (2011) highlighted that the TPACK model is easy to comprehend at the surface; nevertheless, any attempt to go beyond its surface of simplicity reveals the complexity that the model so easily hides. Irrespective of the criticisms that the TPACK framework has received, its potential for providing researchers, teachers and educators with a roadmap to theorise how ICT can be integrated to make teaching and learning more effective as Archambault and Barnett (2010) acknowledged, cannot be ignored neither the context in which the TPACK model is situated.

### **2.4.3. TPACK in the context of the study**

In this study, TPACK was employed as the kind of ICT-oriented knowledge needed to transform a teacher-centred approach of teaching physics at the Ghanaian SHSs into a learner-centred approach to bring about interactive teaching and learning with simulations. Consequently, TPACK was considered as the knowledge that teachers need to drive the interactive prospects with ICT (simulations) and design simulations-supported lesson materials for physics. TPACK was conceptualised (see Figure 2.3) as the framework for tracking pre-service physics teachers' developed ICT-oriented competencies. In particular, the technology (i.e., ICT tool) that was learned and explored by the prospective teachers were 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 as a vehicle for driving a constructivist-oriented teaching and learning; enhances the efforts of a teacher (Wieman, Adams, Loeblein & Perkins, 2010); and provokes independent and critical thinking (Wieman, Perkins & Adams, 2007). The content (i.e., subject matter) was physics which was also the pre-service teachers' teaching subject area. For the pedagogical component in the TPACK model, the study adopted an interactive strategy that is constructive in nature as depicted in Figure 2.1. In this regard, the simulations-supported lessons were designed purposely to be technology-oriented, highly inquiry-driven though guided, and activity-based. The pedagogical approach was chosen on the premise that meaningful learning engages activity and also requires some level of interactivity that encompasses active, constructive, authentic and intentional ways of learning. This is supported by Mayer's (2004) interpretation of the constructivist perspective of learning which is taken to imply an active process. Agyei (2012:13) explains Mayer's interpretation to mean that "students must be active during learning". These ideas in the context of this study, emphasise learner-centred approach to teaching and thus, reflect interactive teaching in a constructivist outfit.

In this subsection, the TPACK framework as adapted for the current study has been discussed in a way that situates it as the type of knowledge required to create a constructivist-oriented type of teaching in order to promote interactivity in high school

physics classrooms (in Ghana) and also, design ICT-based intervention for physics instruction. In this context as depicted in Figure 2.3, the TPACK framework was adapted with emphasis on PhET simulations as the technological tool— taking into consideration how it influences the instructional method as well as the content (i.e., physics) in a constructivist manner. The pedagogical approach adopted was associated with Howland et al.'s (2012) model on meaningful learning with technology. This is extensively discussed in subsection section 2.4.4.



**Figure 2.3: Operationalised TPACK for the study with emphasis on the technology-oriented constructs (Adapted from Agyei, 2012: 118).**

An important element considered in this study for situating TPACK as the driving force for interactive teaching was the Design Team (DT) approach. Studies in literature (e.g.,

Agyei, 2012; Angeli & Valanides, 2005; Koehler & Mishra, 2005; Koehler, Mishra & Yahya, 2007) advocate DT approach as an essential ingredient for the development of teachers' TPACK in that, DT: a) affords collaborative learning environment that positions pre-service teachers to go beyond learning about technology to actively involve them to become practitioners (Koehler et al., 2007); b) provides an authentic platform for prospective teachers to acquire the necessary knowledge and skills to teach effectively with technology. This is essential for the projection of the potentials that technology possesses in relation to education (Angeli & Valanides, 2005); c) enables a shift (on the part of teachers) from envisioning technology, pedagogy and content as isolated constructs to appreciating the connective nature of these constructs in relation to the TPACK framework (Koehler & Mishra, 2005). Agyei (2012) adds that learning technology by means of Design Teams or collaborative design puts "pre-service teachers on a common ground as they work collaboratively in small groups to develop technological solutions to authentic pedagogical problem" (Agyei, 2012:72). These highlights from literature suggest that DT is key to developing pre-service teachers' TPACK competencies. Hence, this study, the pre-service teachers were introduced to the concept of Design Teams approach during the initial training workshop of the professional development arrangement (i.e., in the evaluation and implementation stage). This was purposed to help the participants appreciate the usefulness as well as implications of DT approach for the design of ICT-supported interventions. The DT approach was deemed relevant for equipping the pre-service teachers with the practical knowledge of how the *Cooperative* dimension in the 5DML-ICT (Howland et al., 2012) could be brought to light through team work. In addition, the adoption of the DT approach was meant to collaboratively and "actively involve the pre-service teachers in the design of curriculum materials to develop their TPACK" (Agyei, 2012:72).

#### **2.4.4. Meaningful learning with ICT**

Meaningful learning has been described in different terms as a way of learning that makes learners to acquire new knowledge or understand new information or concept based on what they already know as well as their personal experiences (Jonassen, Howland, Marra

& Crismond, 2008). By this description, meaningful learning could be said to echo constructivism as it promotes meaning making on the part of learners. Literature (Jonassen et al., 2008; Howland et al., 2012) highlight five components of meaningful learning: *Active*, *Constructive*, *Intentional*, *Authentic* and *Cooperative*. In Jonassen et al.'s (2008) view, these attributes of meaningful learning are “interrelated, interactive, and interdependent”. This means that they do not exist in isolation for meaningful learning to be achieved, rather it is their synergetic effect that has value for instructional and learning purposes. This seems to suggest that teaching and learning artefacts when considered for meaningful learning should be designed to promote active, constructive, intentional, authentic and cooperative learning. This is evident in the descriptions the authors gave for each proposed attribute. In particular, Jonassen et al. (2008:7) explained *Active* to mean “manipulative and observant” in that learners are engaged actively in an environment that allows them to manipulate objects and parameters and also, learners are privileged to observe the results of their manipulations accordingly. However, authors added that 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” (Jonassen et al., 2008:7). On these grounds, the authors described the *Active* and *Constructive* attributes of meaningful learning to be “symbiotic” in that, they both depend on each other for meaningful learning to be achieved. 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 in order to appreciate how the *Active* attribute/dimension when operationalised influences the *Constructive* and vice versa. This could be crucial for the identification of elements that uniquely define the two dimensions explicitly. With the *Intentional* attribute, Jonassen et al., (2008:7) posited that meaningful learning is “reflective and regulatory”—the emphasis here was on achieving a cognitive goal. Thus, whatever activity students are engaged in for knowledge construction, it 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. The *Authentic* attribute was articulated by authors 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 the real-world contexts. Finally, the *Cooperative* attribute, as described by authors involves collaboration propelled by conversations; providing an atmosphere where learners could learn from each other in order to appreciate different ways of seeing the world.

Technology is not left out of the meaningful learning picture. According to Jonassen et al. (2008) each of these attributes can be realised with the aid of instructional technologies. Howland et al. (2012) agreed to this fact by recognising the important role that technology play in achieving meaningful learning. Howland and colleagues thus, described these aforementioned attributes of meaningful learning as the “five dimensions of meaningful learning with ICT”— positioning ICT as the vehicle by which meaningful learning is brought to bear in the classroom. In this study, Howland et al.’s (2012) idea about ICT as the vehicular tool for enabling meaningful learning was of interest. Consequently, Howland et al.’s (2012) five dimensions were employed and adapted in line with Koh (2013) as a lens to characterise and define interactive teaching and learning of physics with ICT (simulations). According to Koh (2013), the five dimensions by Howland et al. (2012) include: a) Active, b) Constructive, c) Authentic d) Intentional, and e) Cooperative. Koh further highlighted that there were problems to be resolved in any attempt to operationalise each dimension in consideration of “teachers’ TPACK for meaningful learning with ICT” (Koh, 2013:887). Issues raised in this respect 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 et al. (2003:7)’s assertion that “activity is necessary but not sufficient for meaningful learning”. The issue raise in this regard seems to suggest a possible relationship between the *Active* and *Constructive* dimensions 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*.

- 2) there should be evidence of how lesson activities developed and designed by teachers aim at involving students in ways that help them to 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, 2013:889) in the *Authentic* dimension; and
- 4) the use of divergent tasks as indicated by Harris et al. (2009) would best represent the prospects of the *Cooperative* dimension (Koh, 2013).

By considering these propositions made by Koh and informed by Koh’s (2013:893) “Rubric for assessing TPACK for meaningful learning with ICT”, Howland et al.’s (2012) proposed 5DML-ICT was adapted and conceptualised taking into consideration how these ideas inform the way a teacher teaches in a constructivist manner. Consequently, the following operationalisation were made and used to measure the effectiveness of the ICT-based interventions designed in this study:

- *Active*: the use of PhET simulations in lesson activities designed to engage learners in learning the subject matter:
- *Constructive*: the use of PhET simulation in lesson activities designed to stimulate students to reflect upon the subject matter and express their ideas and meaning beyond what is presented them.
- *Authentic*: the use of PhET simulation in lesson activities to connect to students’ personal experiences to real-world.
- *Intentional*: the use of PhET simulation in lesson activities to engage students in diagnosis, evaluation, and improvement of the learning gap.
- *Cooperative*: the use of PhET simulation in lesson activities to engage students in group work for divergent knowledge expressions.

Based on the theoretical frameworks discussed so far, the study proposed the conceptual framework: “TPACK for interactive teaching and learning with ICT( PhET simulations)” as shown in Figure 2.1. The proposed framework was therefore framed in this study on the basis that interactive teaching as defined and characterised by the 5DML-ICT model is deeply rooted in the constructivist ideologies—which also have direct influence on the

type of knowledge required (on the part of the teacher) to drive the interactive prospects with ICT. On these grounds, interactive teaching was defined for the context of the study to mean: an instructional 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 atmosphere.

## **2.5. Gaps in the literature**

Literature reviewed in this chapter identified three major issues that have called for the need for research work in tracking the development of pre-service teachers' competencies as they endeavor to integrate ICT (simulations) into the teaching of physics in the SHS in Ghana. Firstly, the literature review shows that the government of the Republic of Ghana does appreciate the importance of using teaching methods that are student-centred in nature for the teaching of science (physics). This has been shown to be evident in the senior high school physics curriculum (i.e., GPC4SHS) as developed by the MOE (Ghana) since the GPC4SHS stipulates that teachers should avoid teaching strategies that promote rote learning and embrace methods that encourage student to take ownership of their learning (MOE, 2010). Irrespective of these, literature shows that the dominant method adopted for teaching physics in Ghana is purely teacher-centred. Teachers' affection for the teacher-centred approach has been shown in the literature to be deeply rooted in the way they have been trained in the teacher training institutions in Ghana. The consequence of this action has been described in literature as a major cause of the poor performance in physics in recent years at the SHS level in Ghana and the dwindling interest in the subject. A shift from the teacher-dominated to a learner-centred approach is what literature (Voogt, 2003) recommends; even though not much attention has been paid to determine how this shift in paradigm could be effectively realised. Furthermore, in the Ghanaian context, research conducted (e.g., Antwi, 2013) for the purpose of ascertaining improvements in the teaching of physics in a manner that promotes student-centred way of teaching has not been peculiar to the senior high school level.

Secondly, literature reviewed in this chapter projects ICT, specifically, simulations as a probable interactive tool for enforcing and creating a constructivist-oriented classroom for teaching science (physics). Most of the literature discussed herein have been in relation to how simulations have been used in the developed countries for the teaching of physics; not to mention its potentials in light of explorations and studies done in developed countries. The PhET simulations, for example apart from being developed by a research group in the USA, there exists a lot of literature as discussed earlier in this chapter on how it has been explored for teaching science, mostly physics. Seemingly, existing literature has failed at looking at its potentials from the perspective of the less developed countries which Ghana forms part of; even though such a step if taken has the potential to provide valuable insights to the developers of the PhETs in upgrading its interfaces to be more context-friendly and thus, to help find solutions to unforeseen barriers to the PhETs' effective usage world-wide.

Thirdly, literature highlights in different ways that the teacher's role is important for any educational change anticipated in science teaching. The change sought in this regard is believed to be complex and highly dependent on teachers in terms of their knowledge of the subject matter they are expected to master, the pedagogy they are to adopt and the technology they are to employ for any good teaching to be realised in addition to the interrelationships that exist between and among them (Mishra & Koehler, 2006). These are important ingredients for effective and interactive teaching of science (physics) targeting the learner as the element of attention when the teachers in question have been well equipped with the required knowledge. Nevertheless, what is missing in the literature is a mechanism that explores and tracks the development of science (physics) teachers' (both in-service and pre-service) knowledge and skills (but not restricted to them) in their pursuit of a "good teaching" as mentioned by Mishra and Koehler (2006) mediated by ICT.

In light of these gaps, the present study sought to add to the existing body of knowledge by:

- exploring how ICT (PhET simulations to be specific) can be used to facilitate the creation of interactive environment that is deeply rooted in constructivist ideas about meaningful learning for effective teaching and learning of physics at the SHS level in Ghana. This was purposed to help determine the ICT-based intervention that best fitted the Ghanaian SHS classrooms;
- tracking the development of pre-service teachers through a professional development arrangement (PDA) as they developed their competencies for integrating an ICT tool like PhET simulations into the teaching of high school physics. This was aimed at:
  1. providing a benchmark for gaining insight into how the pre-service teachers shifted from the teacher-centred approach that their current training seems to have subjected them to, to a learner-centred approach that is interactive and purposed to stimulate knowledge construction in the SHS physics classrooms in Ghana; and
  2. refining the initial design guidelines that guided the design of the ICT-based intervention for the provision of: a) an understanding into how the pre-service teachers improved their teaching, b) an explanation for how students' learning was enhanced, and c) a stepwise approach on how the PhETs could be used effectively in physics classrooms for meaningful learning outcomes.

## **2.6. Summary of chapter**

In this chapter, literature was reviewed with respect to the topic chosen for the present study. The review began by giving a detailed overview about physics education in Ghana in relation to: the stipulations of the existing and current Ghanaian SHS physics curriculum as well as its implication for students and teachers; the nature of teacher preparation programmes as ran by the two major higher education institutions that are mandated to train pre-service teachers to teach science at the SHS level. In addition, the literature reviewed herein, examined ICT's use in education; expounding on its affordances. PhET simulations were also examined in this chapter for its remarkable features and potentials for promoting interactive teaching of physics and situated to be

appropriate for the study. In the later part of this chapter, theories (i.e., constructivism, TPACK framework, and the five dimensions for meaningful learning with ICT) that underpinned the present study was discussed. In particular, a detailed description of how each of these theories informed the proposed conceptualised framework was given and established using the literature reviewed on these theories as a lens. Finally, I ended the literature review in this chapter with discussions to highlight the gaps that were identified in the course of the review using the topic chosen for this PhD thesis as a guide.

The next chapter is written to give an in-depth account of the research approach and design employed for the study; keeping track of how the professional development arrangement adopted for the study was used as a platform for understanding pre-service teachers' process of development as they strived to integrate ICT (simulations) into the teaching of high school physics in a manner that was activity-driven and student-oriented.

### **3. CHAPTER 3: RESEARCH METHODOLOGY**

#### **3.0. Introduction**

The main goal of the study was to explore and understand how the process of development of pre-service teachers' competencies for integrating ICT in the teaching of high school physics can be explained. In particular, PhET simulations were used as the interactive ICT tool by which teachers developed ICT-oriented lesson artefacts for effective and interactive teaching of physics. To achieve this goal, three research questions were examined. These were: (1) What ICT interventions can be designed to fit the realities in the SHS classroom in a manner that makes the teaching of physics interactive in Ghana? (2) How effective is the ICT intervention in improving teaching and enhancing students' understanding of concepts in physics? and (3) How can the improvements in teaching and enhanced student understanding of physics concepts be understood and/or explained? In this study, each of the three research questions were denoted by RQ1, RQ2, and RQ3 respectively. These three research questions were examined to provide an answer to the underlying research question: "How can the process of development of pre-service teachers' competencies for integrating ICT in the teaching and learning of high school physics in Ghana, using simulations as an interactive tool be understood?". Different research methods, instruments, and data collection procedures were employed in the study in ways that complemented the purpose of the study. It was therefore appropriate to account for how the purpose of the study was realised; and how each element tasked in the procedures adopted for its execution, limited and/or influenced the findings of the present study. Hence, this chapter presents detailed account of the methodology used in addressing the research questions. Specifically, the research paradigm, research approach, research design, sampling procedure, data collection, data analysis, validity and reliability of instruments used, and ethics considered in the course of the study are the subheadings used in giving a detailed account of how the study was executed. The limitations of the choices of approach were also discussed. Finally, the chapter ends with a summary of all the issues discussed.

### **3.1. Research paradigm**

The approach to research involves not only the distinct method or procedure used, but also the philosophical ideas (paradigm) that inform the nature of the research conducted. It is therefore important to bring to bear the paradigm that underpinned this research. Interpretivism (naturalistic) approach to research was the choice of research paradigm for the study. Literature shows that interpretivists are of the assumption that: 1) “realities are multiple, constructed and holistic”; 2) “the knower and the known are interactive and inseparable”; 3) “only time- and context-bound working hypotheses are possible”; 4) “all entities are in the state of mutual shaping”; and 5) “inquiry is value-bound” (Lincoln & Guba (1985) in Hashemnezhad, 2015:55). These assumptions seem to reflect the definition given to qualitative research in literature, “...an inquiry process of understanding a social or human problem based on building a complex, holistic picture formed with words, reporting detailed views of informants, and conducted in a natural setting” (Creswell, 1994:1-2). This makes the interpretivism paradigm well positioned for adopting a case study design as the strategy for inquiry in this study. In addition, the features of a Design-Based Research (DBR) approach employed in the study can also be inferred from these assumptions; in that DBR involves conducting research in an authentic setting to involve the collaboration between practitioners and researchers with the goal to develop knowledge that can be used in practice. In this study, the focus of attention was on understanding how pre-service teachers developed their competencies. This can once again be linked to interpretivism. Researchers like Cousin (2005) and Elliott and Lukes (2008) emphasised that when interpretivism is adopted as the philosophical basis for research, the primary focus of attention is on understanding because it is positioned between an individual and an event. This notion was also corroborated by Lather (2006) as he attributed interpretivism to the word “understanding”. Consequently, the ontological position of this study was that reality is neither singular nor objective, but inter-subjective with emphasis on meanings and understanding within the context of a specific society. Therefore, meaning in this context, does not exist independent of the learner, but rather can be gained through the personal experiences that are ideas-driven. This situates the way of knowing to be a constructive process that calls for adjustments in instructional

strategies in a manner that provides avenues for learners to make use of their previous knowledge and become active participants of the teaching and learning process. On these grounds, the professional development arrangement (PDA) (see Figure 3.3) for the study was entrenched in the principles of TPACK and the 5DML-ICT theories; mediated by simulations as the interactive ICT tool and situated within the philosophical ideas of the interpretive paradigm.

As mentioned earlier, multiple sources of data collected during the PDA were largely qualitative in nature, but also included survey data. This does not outweigh the interpretivist stance. Glesne and Peshkin (1992) explain interpretivism as having different assumptions of the nature of the world from that of other paradigms and does not presume that the interpretivists never use a survey. According to these researchers, a survey may be used, but for supplementary purposes (which was the case for this study). This facilitated triangulation of the data collection strategies.

In the next sections (i.e., 3.2. and 3.3.), the Design-Based Research approach and the case study research design are discussed to give an account of how the study was conducted.

### **3.2. Research approach**

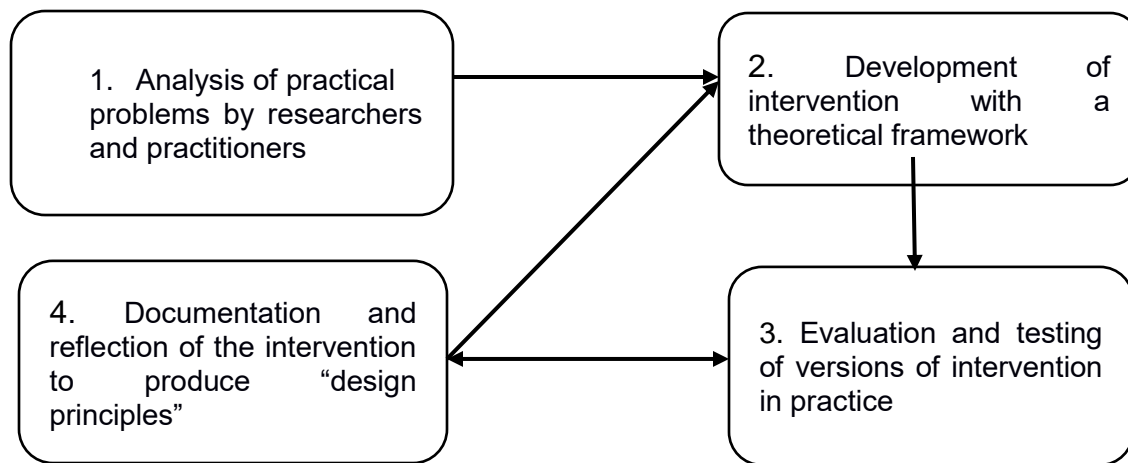
Design-Based Research (DBR) was employed as the research approach for the study. Its remarkable potentials for bringing about practical solutions for complex problem in educational practice through research, design, and practice (Parker, 2011) is what informed the researchers' choice. According to the DBR Collective (2003:5), DBR is the methodology to adopt when a research work is aimed at "... understanding how, when and why educational innovations work in practice". This situated DBR as an appropriate approach for tracking how the pre-service teachers developed their knowledge and skills for integrating ICT into the teaching of physics using simulation as the interactive tool. Furthermore, DBR was used purposely to improve, and not to prove educational practice (Reeves, 2006). DBR is described in literature as an intervention (Design-Based Research Collective, 2003), iterative process (Easterday, Lewis & Gerber, 2014), and theory-oriented (Cobb, Confrey, diSessa, Lehrer & Schauble, 2003). These characteristics of DBR were deemed relevant for facilitating a design process that is theory-driven and leads to theory development in this research. Thus, the DBR approach adopted for the study was propelled beyond the design and testing of the intervention in order to explore its effectiveness in practice.

The rationale for employing Design-Based Research for the study was to focus on constructing and validating an instructional ICT intervention for the purpose of producing a realistic solution to the non-interactive methods of instruction being adopted for the teaching of physics in Ghana. Among other reasons which explained the adoption of the DBR approach in this study were as follows:

- The study was conducted within "a single setting over a long time. It underwent iterative cycles of design, enactment, analysis, and redesign" (Wang & Hannafin, 2005: 9).
- Formative assessment was used throughout the study to provide feedback that was used in modifying, analysing, and evaluating the design. Through reflection of the whole DBR approach, the intervention was evaluated to ascertain the extent to which it could be used to achieve desired learning

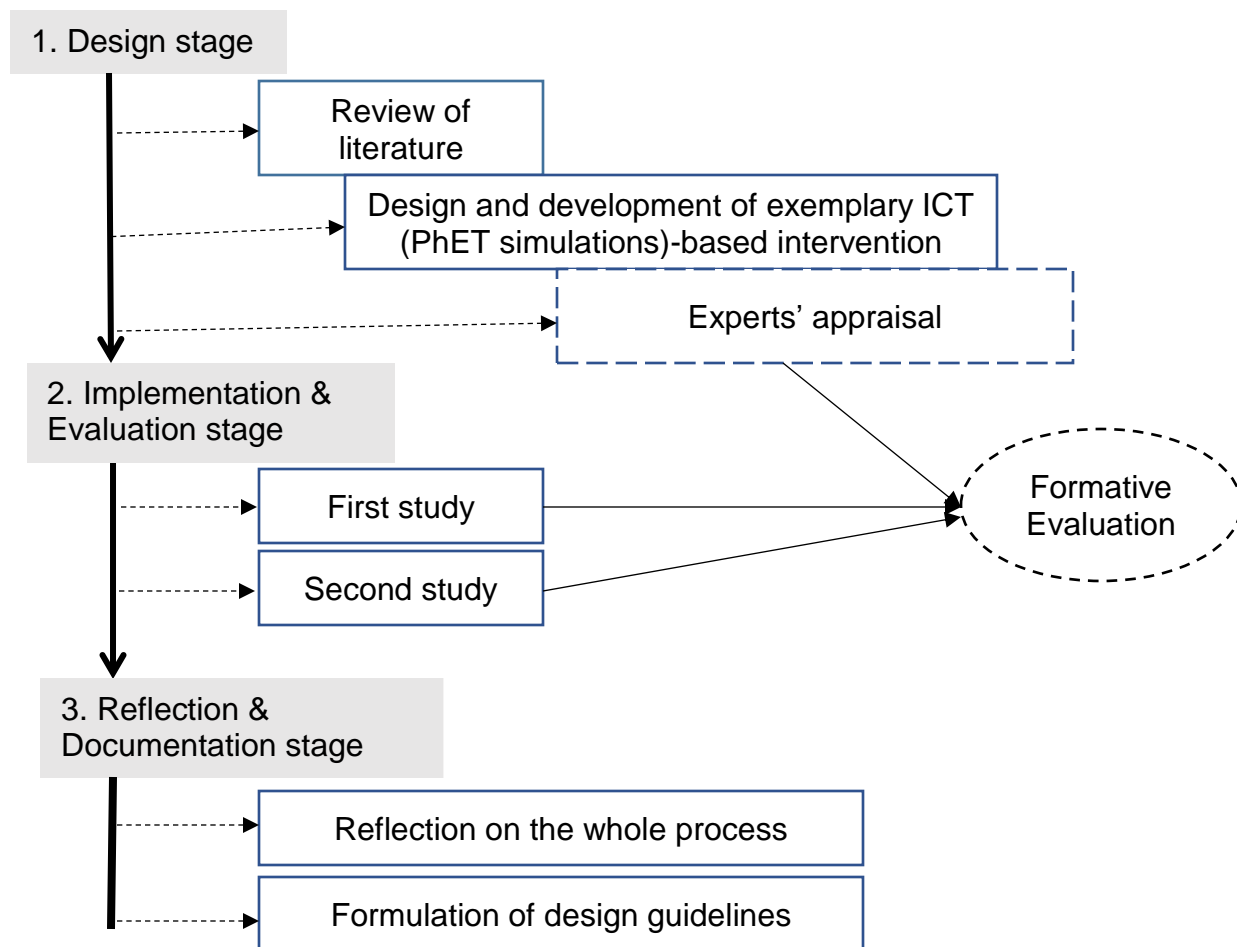
objectives and learning outcomes.

The present study was built on the framework of DBR described in the light of Reeves' (2006) stages as shown in Figure 3.1. and modified for the study. Reeves' idea about the stages involved in a DBR capitalises on the importance of feedback in a DBR approach; in that the feedback from every stage of the design could be a guide for improving the quality of an intervention. Also, as depicted by Figure 3.1, the feedback does not only influence the quality of the intervention designed, but also informs the refinement of the design principles.



**Figure 3.1 Reeves's (2006) Stages of Design-Based Research.**

By adopting and modifying Reeves' (2006) idea about DBR, three stages: the design stage, the implementation and evaluation stage, and the documentation and reflection stage were considered in this study. The first stage of the four stages of DBR as proposed by Reeves was not included in the study. This was because the practical problem to be addressed in relation to the Ghanaian context has already been established through literature review (see chapters 1 and 2), Figure 3.2 represents the nature of the DBR approach adapted for the study.



**Figure 3.2 Design-Based Research arrangement adapted for the study.**

In the next subsections, details of what went into each one of three stages in the DBR process as adapted for the study are discussed.

### **3.2.1. Design stage**

The design stage was aimed at addressing the first research question, RQ1: What ICT interventions can be designed to fit the realities in the SHS classroom in a manner that makes the teaching of physics interactive in Ghana? This stage was in three parts: (1) Literature review, (2) Design of the exemplary ICT intervention, and (3) Expert appraisal. Literature was reviewed in order for the researcher to come up with the initial design guidelines that informed the researcher on the choice of the appropriate technology (ICT),

pedagogy, and content for the development of an ICT-based intervention. In this context, PhET simulations were used as the technological tool. The use of the PhETs in this study was appropriate in that, it is an application that is readily available, has the potential to be sustained, affords interactivity as a vehicle for driving a constructivist-oriented teaching and learning of physics at the high schools in Ghana, and it is user friendly. The choice of pedagogical approach was chosen on the premise that for meaningful learning to be realised, there should exist some level of engagement through activity. This emphasises learner-centred approach to teaching and thus, reflects interactive teaching. Informed by these ideas among others (which constituted the initial design guidelines), the researcher developed and produced two sets of the designs [ICT (simulations)-based lessons in physics] (see APPENDIX D) as the intervention based on the Ghanaian physics curriculum for SHS (GPC4SHS). In this study, the interventions were referred to as PhET simulations-supported physics lessons (PSSPLs). The PSSPLs were given to two experts to appraise in order to ensure its practicability and improve its validity. These were experts in the areas of instructional design, physics education and ICT integration. The views and suggestions from the experts were then used to improve the quality of the PSSPLs and also, used to inform the formulation of the initial design guidelines. Thus, the experts' appraisal was valuable in refining the exemplary interventions and the initial guidelines. The final intervention developed at the design stage consisted of two simulations-supported lessons that were activity-based and covered two topics—Wave motion and Thin lenses from the GPC4SHS. The two interventions were developed based on PhET simulations [also referred to as sims (Wieman, Adams, Loeblein & Perkins, 2010), PhETs or simulations in this study]. The selected physics topics were used as the criteria for choosing the sims environments. As the sims are readily available, they were downloaded from an online repository (i.e., <http://phet.colorado.edu>), used offline and explored for the design of the interventions.

### **3.2.2. Implementation and evaluation stage**

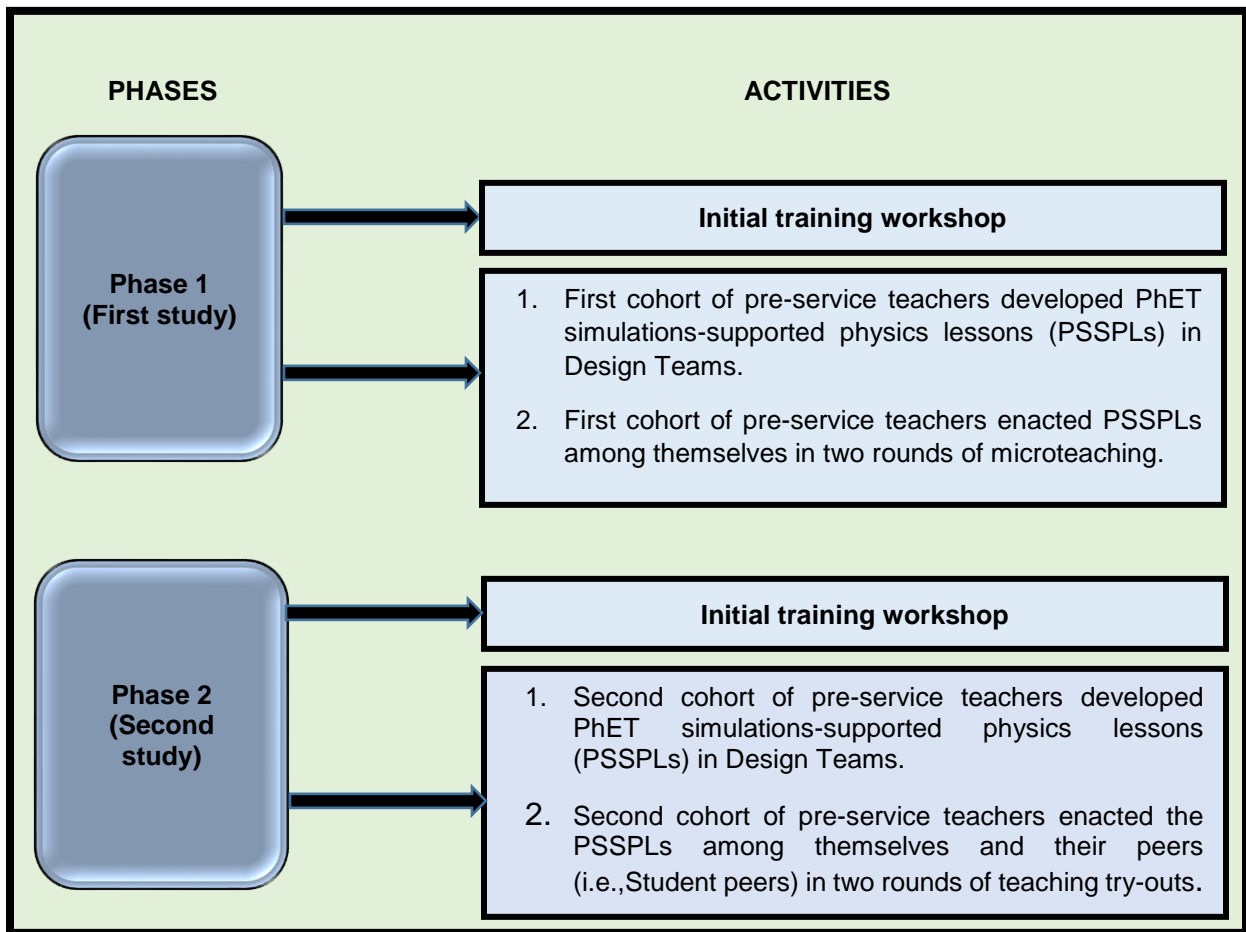
The main purpose for the implementation and evaluation stage (second stage) was to describe the extent to which the designed intervention was delivered as intended. At this

stage, there was an iterative stage of formative evaluation and re-design. Hence, the second stage of the study was aimed at addressing the research question, RQ2: How effective is the ICT intervention in improving teaching and enhancing students' understanding of concepts in physics?

The implementation and evaluation stage involved a professional development arrangement (PDA) (see Table 3.1). The aim of PDA was to train and help eight pre-service physics teachers acquire ICT-oriented competencies in integrating ICT (PhET simulations) in the teaching of high school physics. In particular, the PDA constituted two phases: 1) a first study— namely, Phase 1; and 2) a second study—namely, Phase 2. Both phases 1 and 2 were purposed to ascertain an iterative cycle of formative evaluation and redesign in the study in order to allow for a systematic refinement of the intervention developed. Each of these phases began with an introductory training workshop. Hence, for each cohort of pre-service physics teachers considered for Phase 1 and Phase 2, the PDA organised for them was in two parts— an aspect which involved the initial training workshop and another where the participants were tasked to design, develop, and implement their own ICT-based interventions based on their personal experiences with the exemplary curriculum materials I designed. Figure 3.3 gives an overview of the activities involved at each phase of the PDA.

Components of the initial training workshop were as follows:

- Presentation/discussions on TPACK framework, “Five dimensions for meaningful learning with ICT” as a basis for interactive teaching, and Design Team approach.
- Introduction to PhET simulations.
- Hands-on activity on PhET simulations by Design Team.
- Demonstration of PSSPLs (exemplary materials) by researcher.



**Figure 3.3 Professional development arrangement adapted for the study**

It is important to mention that at this stage of the study, both cohorts of pre-service physics teachers worked in Design Teams to explore the PhET simulation environments that were peculiar to the selected physics content using the GPC4SHS (MOE, 2010) as a guide. They also worked in Design Teams to develop the PSSPLs. In both Phase 1 and Phase 2 of the study, there were two teams each— namely: Design Team A1 and Design Team B1; and Design Team A2 and Design Team B2 respectively. There were however no criteria set for grouping them into these Design Teams as the participants formed their own Design Teams based on their sitting positions at the first day of the PDA. Their default sitting positions were therefore maintained throughout the PDA. In particular, Team A1, A2 and B2 comprised of two male pre-service physics teachers each while Team B1

constituted one male and one female pre-service physics teachers. In all, four Design Teams were involved and engaged actively at this stage of the study.

In the subsections that follow, I give a vivid account of the PDA as it unfolded in the evaluation and implementation stage of the study.

### **3.2.2.1. Overview of the initial training workshop**

The initial training workshop for both the first and second studies was purposed for the participating physics pre-service teachers to develop an understanding into the underlying theories that underpinned the development of an ICT-based intervention. In addition, the initial workshop was meant to expose the participants to various student-centred teaching strategies that could be adopted for teaching high school physics with ICT (PhET simulations) in order to promote interactivity in the physics classroom and also, enhance students' learning outcomes in Ghana. The theories considered for this PDA during the initial workshop included: 1) Technological Pedagogical and Content Knowledge (TPACK) framework (Mishra & Koehler, 2006) and 2) "Five dimensions for meaningful learning with ICT" (5DML-ICT) model (Howland et al., 2012 as adapted by Koh (2013)). Amid presentations and discussions, the participants were groomed and exposed to what these theories represent as well as the various ways in which each of these theories informed: a) the design of ICT-based interventions specific to physics at the high school level, b) the extent to which pre-lesson preparations with ICT unfold, and C) the teaching and learning strategy to adopt in using ICT. In particular, the 5DML-ICT was introduced to the pre-service physics teachers mainly as the theory underpinning a constructivist-oriented interactive teaching approach. This was because, the current study among other objectives, was aimed at exploring pre-service teachers' experience in developing ICT (simulations)-based physics lesson artefacts as well as implementing it in a constructivist environment. Constructivism in this respect informed interactive teaching. Thus, the pre-service teachers during the PDA were introduced to the "*Active, Constructive, Authentic, Intentional, and Cooperative*" dimensions of the 5DML-ICT model as the key ingredients that characterise interactive teaching with PhET simulations. This was crucial for the development of an ICT (simulation)-based intervention.

Furthermore, the TPACK framework was introduced and discussed as the needed knowledge in order to practice interactive teaching with ICT (simulations). Thus, during the initial workshop, each element of the TPACK model as well as the interrelationships between and among them were discussed extensively for the understanding and applicability of the pre-service teachers. Emphasis was however laid on two things as far as the TPACK model was concerned during the introductory training workshop of the PDA:

1. Conceptualising the TPACK model as a single body of knowledge paying immense attention to how the prospective teachers could develop an understanding of how the interplay between technological knowledge, pedagogical knowledge and content knowledge. Specifically, how the knowledge domains that involve the technology component—TPK, (i.e., knowledge of how to use simulations for teaching in a manner that is interactive and activity-oriented); TCK (i.e., knowledge of using simulations to represent concepts in physics); and TPACK (i.e., Knowledge of using PhET simulations to facilitate the teaching of physics in an interactive manner) could be realised and applied for the development of an effective technology-integrated physics lessons; as noted by Agyei and Voogt (2012), was of interest. To achieve this, the prospective teachers were given sample technology-integrated lesson artefacts (not simulation-based) to identify, discuss, and then come to a consensus about how the interplay between the three knowledge types had been realised and applied by the author of those lesson artefacts. These lesson artefacts (i.e., lesson plans, PowerPoint presentations, activity sheets), though included lessons that were physics-oriented, majority of them were designed for chemistry, biology, and mathematics lessons. These exercises helped the participants to appreciate how the interrelationships in the TPACK have been implemented in other subject areas as well as in physics. The exercises were also aimed at helping the pre-service teachers to get practical example as well as deeper understanding of what it means for a teacher to go beyond using the three domains (i.e., CK, PK and TK) in isolation to emphasising the kind of intersections and relationships that must exist between and among the three knowledge domains.

2. Espousing, in simple terms, what the authors of the TPACK model meant by including and placing much weight on “context” and its implication for the ICT-based intervention that the participants were tasked to develop in the course of the PDA for the Ghanaian classroom situation. Discussions in this respect (during the PDA) were geared towards the state-of-the-art resources that were peculiar to the Ghanaian SHS physics classrooms. Thus, a detailed discussion on “context” in the TPACK model during the PDA was ensured to provide a platform for the participating prospective teachers to reflect on and identify practical and feasible Ghanaian classroom situations they could consider for the design and implementation of the PSSPLs.

Another aspect of the initial workshop of the PDA was the session where the participating pre-service teachers were introduced to Microsoft PowerPoint presentation software as a productivity tool. This was aimed at equipping the participants with the basic presentation skills that will enable them deliver their lessons effectively without unwanted disruptions during the enactment of their ICT-based lessons. The presentation software was also deemed very useful in the Ghanaian context for incorporating simulations into lessons. Its hyperlink feature which provides a link from one document to another on the same computer and even to an online document, videos, audios etc. was useful for the delivery of the lessons. The fact that it is readily available for use and accessible in Ghana was also an added advantage. The focus of its use here was on how it could be used to effectively enact a simulations-based lesson. The introductory session on Microsoft PowerPoint presentation software during the PDA was mainly activity-based. In this session, the prospective teachers learned to prepare PowerPoint presentations and practiced through a series of hands-on activities to use it effectively as an instructional tool. They used a training manual on PowerPoint presentation (developed by the Centre for Teaching Support, University of Cape Coast) as a guide in developing their presentation skills during this session. However, where they had challenges, I assisted. It is important to emphasise at this point that, the PowerPoint presentation software is also an ICT tool, but it was not the technological tool of utmost interest even though it was considered as a necessary technological resource for the enactment of the PSSPLs—hence, the sole reason for its inclusion in the PDA.

The core of the initial workshop before the design and implementation of the PSSPLs, was the sessions that introduced the first and second cohorts of pre-service teachers to: 1) PhET simulations and 2) lesson artefacts development as prescribed in this study. In particular, PhET simulations of the participants' choices were selected in line with selected topics in the Physics curriculum for Ghanaian SHS and extensively explored by the participants to determine its affordances for effective teaching of selected physics topics. The session with the PhETs was purposed for the pre-service teachers to connect their prior physics knowledge to the simulation environments. This informed them about the topic to choose, the lesson objectives to consider, the kind of activities to develop with the simulations and the teaching approach to adopt. The focus in this regard was to guide them through exploratory hand-on exercises in order for them to appreciate the affordances of the PhET simulation environments in representing the subject matter. This session involved a lot of discussions with the participants which were crucial to me especially, in understanding how the participating pre-service teachers developed their competencies in using simulations for teaching physics in an interactive manner.

A lesson artefact development session was added as a component of the initial training workshop. This was purposed to discuss concepts such as lesson plan, activity sheets, as well as presentation slides' development for effective delivery/presentation of lesson. This session was also designed to help the participants appreciate how the 5DML-ICT model informs the development of these lesson artefacts for interactive teaching to be realised in a way that enforces knowledge construction on the part of learners. The participants were therefore engaged in a series of activities and discussions that were meant to shape their understanding of what a lesson plan, activity sheet and other lesson artefacts mentioned herein entailed with much emphasis on the creation of a learner-centred teaching and learning environment which is aimed at promoting a constructivist ICT-oriented physics classroom. In addition, the need for alignment of these lesson artefacts was also discussed as a key ingredient for the design and implementation of the ICT (simulations)-based intervention. This was intended to help the pre-service teachers connect their ideas from one lesson artefact to another informed by: 1) the selected lesson

objectives, 2) the affordances of the simulation environment of choice, and 3) the physics content as prescribed in the GPC4SHS document.

Finally, the initial workshop for each cohort of pre-service physics teachers ended with a demonstration of the exemplary intervention (designed during the design stage). This was after the first two drafts (see APPENDIX D) of intervention had been appraised by experts. At this stage, I tested the exemplary intervention on the two different cohorts of pre-service teachers in two sessions to model and demonstrate its application. The first exemplary try-out session was with the first cohort of pre-service teachers (in Phase 1). The second exemplary try-out session was with the second cohort of pre-service teachers (in Phase 2). The try-outs were intended to facilitate transfer and an understanding of the underlying principles and conditions for the pre-service teachers' application. In addition, the exemplary intervention was meant to give the pre-service teachers practical insights on how all the theories, concepts and ideas as discussed in the initial training workshop governed the development of an ICT-based intervention. The use of exemplary intervention in this study was therefore founded on the notion that it has the capacity to provide teachers with operational understanding of what innovation is about in terms of what technology integration constitutes, and also to give step-by-step "know-how" suggestions about the design process.

#### **3.2.2.2. Overview of the design and implementation of the PhET simulations-supported physics lessons (PSSPLs) by Design Teams in both phases of the PDA**

Based on the experience with the exemplary materials, the participating pre-service physics teachers (i.e., the competencies understudy) developed their own lessons (i.e., PSSPLs) and tested in two rounds of microteaching. The first cohort of pre-service teachers tried out their intervention in two rounds of microteaching among themselves (i.e., among their colleague Design Team members) in Phase 1, where a member of each of the two DTs taught. In a similar arrangement, a different (second) cohort of pre-service

physics teachers also tested their intervention in two rounds of teaching try-outs in Phase 2—which were done first, among themselves (i.e., among their colleague Design Team members), and secondly, among their peers who as mentioned earlier (in Chapter 1) constituted a different group of pre-service teachers (the 2<sup>nd</sup> years) who only served as “learners” and not as the competencies understudy to mimic the roles of high school students. These iterative cycles were meant to help improve the intervention based on the feedback obtained after each try-out. Thus, the evaluation of the design was formative for all two phases of the PDA. The information gathered at this stage necessitated the pre-service teachers to develop a more detailed design for implementation during the first and second study and thus, provided me with the opportunity to refine the initial design guidelines.

Table 3.1 gives an outline of the PDA organised in this study. As can be inferred from Table 3.1, the duration for each study was 17 days. However, the specific days involved for each session differed as the days set for each cohort was subjected to their convenient times. For example, with the second cohort of participants, the 17 days fell within school period (from the second week of September to the first week of November, 2017). As a consequence, the participating pre-service teachers as well as Student peers were only available during their free periods as per their respective academic timetables which also differed. This dragged the proceedings of the PDA. Thus, the 17 days were not continuous for the second study. With first study, the 17 days were spread within a maximum of four weeks (from the last week of May, 2017 to the third week of June, 2017). This arrangement was possible because this cohort of pre-service teachers were on vacation. Though, the timelines for the two phases of the PDA were different, the content discussed for each session of the PDA was the same for each day assigned for each cohort with the exception of the last two days (i.e., days, 16 and 17 see Table 3.1) where, there was a slight difference in terms of the microteaching arrangements made. This was particularly subjected to the convenient times of the Student peers in the second study.

Table 3.1: Summary of professional development arrangement with respect to Phase 1 and Phase 2

Initial training workshop of the PDA				
Day for both Phases 1&2	Facilitator	Content of PDA	Materials used	Instruments administered
Day 1	Researcher  Researcher/external facilitator	<ul style="list-style-type: none"> <li>• Overview of the objectives of the study and what the PDA entails.</li> <li>• Introduction to TPACK framework (involving discussions on the seven TPACK constructs).</li> </ul>	Existing materials from literature.	TPACK self-report questionnaire (pre-survey)
Day 2	Researcher  Researcher	<ul style="list-style-type: none"> <li>• Introduction to and discussions on teacher Design Team approach</li> <li>• Introduction to Microsoft PowerPoint (PPT) Presentation software (i.e., its application as an instructional tool)</li> <li>• Hands-on activities for using PPT as an instructional tool</li> </ul>	Existing materials from literature.	
Day 3	Researcher	<ul style="list-style-type: none"> <li>• Introduction to computer simulations (PhET).</li> <li>• Hands-on activities on selected PhET simulations that are physics-oriented online.</li> <li>• Discussions on how the selected PhET mimic real-life application of phenomena in physics.</li> <li>• Hands-on activities on using PhETs offline.</li> </ul>	Simulations from the PhET website: <a href="http://phet.colorado.edu">http://phet.colorado.edu</a>	
Day 4	Researcher	<ul style="list-style-type: none"> <li>• Exploration of PhET simulations in relation to topics speculated in the GPC4SHS document.</li> <li>• Hands-on activities on physics topics selections based on the PhET simulation environment and how their interactive interfaces influence the choice of lesson objective to be achieved in the classroom.</li> <li>• Discussions on the selected PhETs and its appropriateness for specific physics topics, proposed objectives to be achieved, and the affordances of the PhETs for the creation of an interactive environment for teaching and learning.</li> </ul>	Ghanaian physics Curriculum for SHS (MOE, 2010) PhET simulations <a href="http://phet.colorado.edu">http://phet.colorado.edu</a>	

		<ul style="list-style-type: none"> <li>Discussions on the selection or identification of appropriate teaching and learning resources when using PhET simulations.</li> <li>Discussions on possible and state-of-the-art Ghanaian classroom situations that could best be adopted when using PhET simulations for physics instruction.</li> </ul>		
Day 5	Researcher	<ul style="list-style-type: none"> <li>Short group presentations on simulations-supported lesson activities developed by Design Teams mimicking the real classroom situation.</li> <li>Discussion of group presentations in relation to lesson objectives, teaching and learning resources, affordances of PhET simulations chosen, and the classroom situation being mimicked to fit the Ghanaian physics classrooms.</li> </ul>	<p>Ghanaian physics Curriculum for SHS (MOE, 2010).</p> <p>Simulations from PhET website:  <a href="http://phet.colorado.edu">http://phet.colorado.edu</a></p>	Researcher's logbook
Day 6	Researcher	<ul style="list-style-type: none"> <li>Introduction to the 5DML-ICT model and its potential for enabling interactive teaching.</li> <li>Discussions on how the 5DML-ICT model and the TPACK framework are connected for the design and development of an ICT (simulations)-based intervention.</li> <li>Hand-on activities on identifying the <i>Active, Constructive, Authentic, Intentional</i> and <i>Cooperative</i> in sample simulations-supported lesson activities designed by Design Team.</li> <li>Discussions on the extent to which the lesson activities (i.e., teacher and student activities) projected the 5DML-ICT.</li> </ul>	Existing materials from literature (mainly Howland et al., 2012 and Koh 2013)	<p>Researchers' Logbook</p> <p>Researchers' logbook</p>
Day 7	Researcher	<ul style="list-style-type: none"> <li>Demonstration of exemplary intervention</li> <li>Discussions on the components (i.e., lesson artefacts) of the exemplary intervention and its implementation.</li> </ul>		Researchers' logbook
<b>Second aspect of PDA: Design, development and implementation of PSSPLs by Design Team</b>				
Day 8-12 (six days)	Researcher/ pre-service teachers	Design and development of Simulations-supported physics lessons by Design Teams.	<p>Ghanaian physics Curriculum for SHS.</p> <p>Lesson materials and simulations from PhET website.</p> <p>Lesson artefacts</p>	

			Online resources about the physics content.	
Day 13	Researcher/Pre-service teachers	<ul style="list-style-type: none"> <li>• Enactment of first intervention (PSSPLs) by Design Teams among co-participating pre-service teachers in a first microteaching session</li> <li>• Answering of questionnaire</li> <li>• Focus group discussion on intervention</li> <li>• Face to face interview with the two Design Team members who enacted the lessons for that day.</li> </ul>		<ul style="list-style-type: none"> <li>• Researcher's logbook</li> <li>• Five-dimension survey</li> <li>• Interview guides adapted from Agyei 2012)</li> <li>• Researchers' logbook</li> <li>• Audio recorder</li> <li>• Digital camera</li> </ul>
Day 14 &15	Researcher/Pre-service teachers	Modification/refinement of the first intervention (PSSPLs) designed by Design Teams based on feedbacks from the first microteaching via the interviews, focus group discussions as well as researchers' inputs.		<ul style="list-style-type: none"> <li>•</li> </ul>
Day 16 &17	Researcher/Pre-service teachers	<ul style="list-style-type: none"> <li>• Enactment of the refined intervention by Design Teams among co-participating pre-service teachers in a second microteaching session (this was specific to first cohort of pre-service teachers in the first study)</li> <li>• Enactment of the refined intervention by Design Teams among Student peers in a second microteaching session (this was specific to the second cohort of pre-service teachers in the second study)</li> <li>• Focus group discussion with participating pre-service teachers (for first study)</li> <li>• Focus group discussion with Student peers (for second study)</li> <li>• Face to face interview with the two Design Team members who enacted the refined lessons for the day.</li> <li>• Answering of questionnaire</li> </ul>		<ul style="list-style-type: none"> <li>• Researcher's logbook</li> <li>• Interview guides adapted from Agyei 2012)</li> <li>• TPACK self-report questionnaire (post-survey)</li> <li>• Audio recorder</li> <li>• Digital camera</li> </ul>

		<ul style="list-style-type: none"><li>• Closure of PDA</li></ul>		
Reflections on PDA with participants				

### **3.2.3. Reflection and documentation stage**

This was the final stage of the study and was purposed to address research question, RQ3: How can the improvements in teaching and enhanced student understanding of physics concepts be understood and/or explained? The focus here was for the researcher to go into introspection of the design, development, and try-outs of the intervention as the possible approach for improving pre-service teachers' knowledge in developing ICT based physics lessons in an interactive way by use of simulations. At this stage, a theory (refined and final design guidelines) for the design of an effective PSSPLs was formulated based on the understanding of how the pre-service teachers developed their competencies for designing the PSSPLs. Hence, the formulated design guidelines were used as the benchmark for explaining the improvements in the teaching of physics as well as the enhancements in students' understanding of concepts of physics that occurred during the implementation process.

### **3.3. Research design**

A case study strategy was adopted on the basis that it provides an investigative platform for researchers to examine a contemporary phenomenon in context using multiple data sources (Yin, 2003). In this regard, the case study design was considered appropriate for exploring as well as gaining in-depth understanding of the phenomenon being investigated in this study; that is, the process of development of pre-service teachers' competencies in the use of ICT (i.e., PhET simulations) for effective teaching of high school physics in the context of the Ghanaian SHS classroom. Based on this phenomenon, the pre-service teachers of the study served as the unit of analysis as they were the main entity to be studied (Trochim, 2000). A case study strategy was also fitting for addressing the overall research question which was a "how" question and aimed at understanding the phenomenon of interest within a real-life context. This was founded on Yin's (2003) explanation that a case study is appropriate to use when a "how" or "why" question is being asked about current events. Though, the "what" question is not usually attributed to a case study design, it is believed to be relevant; as clarified by Shavelson

and Townes (2002), when the focus is to address descriptive questions which may also be exploratory (Schell, 1992). Thus, in this study, the “what” question (i.e., RQ1) was pertinent for describing the features of an ICT-based intervention that best fit the realities in the Ghanaian SHS classrooms. This served as a roadmap for gaining in-depth understanding into how the designed PhET simulations-based interventions influenced the preparation of the pre-service teachers to effectively integrate ICT into the teaching of high school physics in an interactive manner.

As the overall research question was explanatory in nature, an explanatory case study was deemed appropriate for understanding the phenomenon considered for this study. Harder (2012:2) highlighted the remarkable potential of explanatory case studies as follows:

“Using both qualitative and quantitative research methods, explanatory case studies not only explore and describe phenomena but can also be used to explain causal relationships and to develop theory”.

These potentials as emphasised by Harder situate the explanatory case study strategy in a DBR approach since the hallmark of the DBR approach is the formulation of theory/design guidelines and hence, makes its use appropriate in this study. The development of the design guidelines in this study was therefore ensured through the provision of an explanation and/or account of how and why improvements in teaching using ICT (PhET simulations) and enhanced students’ learning of physics concepts through the implementation process are possible.

The use of both quantitative and qualitative evidence is also emphasised with explanatory case studies as hinted by Harder (2012). This affirms Yin’s (1984:23) definition of a case study as a strategy “... in which multiple sources of evidence are used”. The current research therefore used quantitative as well as qualitative evidence in explaining the phenomenon under study. However, it is important to stress at this point that the quantitative evidence gathered in this regard were not intended for making statistical

generalisation, but rather were purposed for arriving at a holistic understanding of the phenomenon being considered. Therefore, in this study, the need to make analytical generalisation per the findings also informed the use of the case study design as it was crucial for the formulation theory/design guidelines.

Highly informed by the definition of a case study as an approach which describes an intervention purposed to solve a particular problem (Neale, Thapa & Boyce, 2006), the present study's adoption of a case study design was deemed appropriate in that, the study sought to describe an ICT intervention with the intention to provide an alternative and practical solution to the seemingly non-interactive and purely teacher-centred approaches that were currently being adopted in Ghana for the teaching of physics (Buabeng & Ntow, 2010; Antwi et al., 2015).

#### **3.4. Position of the researcher**

In this study, the researcher designed the first two draft interventions, which served as exemplary PhET simulations-based intervention.

The researcher also acted as a facilitator and an observer. As the facilitator, I guided the pre-service teachers to design PSSPLs in ways that promoted interactive and meaningful teaching and learning with ICT. In this position, I directed and exposed the pre-service teachers to the TPACK framework and how each of its components (Technology, Pedagogy and Content knowledge) could be contextualised for effective design and development of simulations-supported lesson artefacts. I was also positioned to help the participants understand what interactivity in the physics classroom implied and what their roles as teachers were in an interactive teaching and learning environment with simulations.

As an observer, I observed the participating pre-service teachers as they designed and taught themselves in the first study as a way of testing the intervention, and also taught their peers during the second study in a microteaching session. The observation was

mainly for me to take notes on the proceedings of the microteaching as the pre-service teachers enacted their interventions and also, assess their TPACK. Also, by observing, I gained more insights into the data collected during the implementation stage. This was very useful for the analysis of the data gathered for the study using different techniques (e.g., survey and semi-structured interview).

### **3.5. Participants**

A total of 17 pre-service physics teachers participated in the study. Eight of them were the main competencies understudy (also referred to as participating pre-service teachers or Design Teams in this thesis). These included final year (i.e., 4<sup>th</sup> years) pre-service teachers (for the 2016/2017 academic year) as well as third year (3<sup>rd</sup> years) pre-service teachers (for the 2017/2018 academic year) of the Bachelor of Education with specialisation in Science programme at UCC. In selecting the participating pre-service teachers, a purposive sampling was used. This was because characteristics such as accessibility, commitment and seriousness were the criteria for selection and were subjected to the “researcher’s experience and knowledge” of the pre-service teachers (Kothari, 2004). In addition, purposive sampling was favourable in this study as the targeted participants were likely to provide rich information which was vital to answering the research questions (Fraenkel & Wallen, 2006). Among the eight participants, four (the 4<sup>th</sup> years) represented the first cohort of pre-service physics teachers in Phase 1 while the remaining four (the 3<sup>rd</sup> years) represented the second cohort of pre-service teachers in Phase 2 of the implementation and evaluation stage. In the current study, these pre-service teachers worked in Design Teams to develop and implement the PSSPLs among themselves and also, among the Student peers who constituted the remaining nine (9) pre-service teachers. The remaining nine pre-service physics teachers (referred to as Student peers or peers in this thesis) were 2<sup>nd</sup> years of the teacher education (B.Ed. Science) programme at UCC. This group of pre-service teachers served as “learners” only during the second teaching try-out in Phase 2 of the implementation and evaluation stage. This served as the means to mimic the real classroom situation. Hence, instead of high school students as the learners, pre-service teachers were used. This was deemed

appropriate as the targeted audience (units of analysis) for the study were also pre-service teachers. However, it is important to stress once again that the Student peers in this study were not the competencies understudy though their views were considered vital in achieving the study goals.

The pre-service teachers were aged between 19 and 36 with the average age being 28.

The choice of the institution was selected mainly on familiarity basis. This was very useful as it enabled me, the researcher to have good access to infrastructural as well as human resources. This affirms Rose, Spinks and Canhoto's (2015) notion that an important ingredient in a case study design is the researcher's ability to easily access his/her case. Thus, familiarity with the study context was crucial for acquiring rich evidence which enhanced the interpretation of the phenomenon explored.

### **3.6. Ethical issues**

In this study, respect for the participants and ensuring that the participants were not offended in the course of the study were of great concern to me. According to Hamilton and Corbett-Whittier (2013), ethical practices should be exhibited in all stages of research. Therefore, in this study, a number of precautions were taken to ensure that throughout the study, ethical issues were prioritised.

First of all, clearance was sought from the University of Free State, Education Ethics Committee (see APPENDIX G). The insightful suggestions and comments made by the committee were valuable in shaping the content and protocol of the entire study.

Consent was sought from the Head of the Department of Science Education (DSE), UCC. This was done by verbally enlightening the Head about the purpose of the study. This resulted in him giving his informal consent. Afterwards, an Information Sheet detailing the professional development arrangement of the study was personally delivered to the department for a written consent. After a careful review of the Information Sheet, a formal

letter was issued from the department granting me the permission to embark on the study and also, to use and access the available resources (e.g., ICT facility) in the department.

After both informal and formal consent had been sought and granted from the department (i.e., DSE), UCC, the pre-service physics teachers (both the participating pre-service teachers and the Student peers) were contacted for their voluntary participation in the study. In order not to coerce them into participating, the pre-service teachers were given in advance, the Information Sheet and Consent Form to enable them decide as to whether to participate in the study or not. The anonymity of the participants was protected by assigning letters and numbers to participants and ensuring that participants did not indicate their names on the administered questionnaires. The participants were also assured that any information they gave out was going to be used in the current research; making sure that their identities were not revealed.

### 3.7. Data collection

In this study, data were collected using questionnaires (i.e., surveys), focus group discussions/interviews, semi-structured interviews, observations and pre- and post-tests. Lesson artefacts such as the lesson plan, presentation slides, and activity sheets developed by the pre-service teachers were also used. The questionnaires used in the study included the TPACK self-assessment instrument also referred to as TPACK survey (adapted from Schmidt et al. (2009a)). This was used to track the change in pre-service teachers developed ICT-oriented knowledge. The questionnaire comprised 38 items (see APPENDIX A (A1)) grouped under seven (7) constructs namely: “Technology knowledge (TK), Pedagogy Knowledge (PK), Content Knowledge (CK), Pedagogical Content Knowledge (PCK), Technology Content Knowledge (TCK), Technology pedagogical Knowledge (TPK) and Technological Pedagogical and Content Knowledge (TPACK)”. In particular, TK= 7, PK=7, CK = 5, PCK = 5, TCK = 3, TPK = 7, and TPACK = 5 items. With a Cronbach’s alpha 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 out of the seven constructs of the TPACK framework, the instrument was considered as valid and reliable. Items were therefore adopted and modified specifically to address integration of simulations in the teaching of physics. The questionnaire (TPACK survey) was given to the participants twice — prior and after the enactment of the simulations-supported lessons. This helped to determine the pre-service teachers’ developed knowledge (TPACK) in relation to ICT integration.

To measure the extent of interactivity considered by the pre-service teachers in the design of the ICT-based intervention, another questionnaire; namely, Five-dimension survey (see APPENDIX A (A2)) was designed to include items adapted from Koh’s (2013:893) “rubric for assessing TPACK for meaningful learning with ICT”. This questionnaire comprised 29 items grouped under the *Active* (6 items), *Constructive* (6 items), *Authentic* (6 items), *Intentional* (4 items) and *Cooperative* (7 items) dimensions. This questionnaire was administered only after the intervention had been enacted for the first time for the pre-service teachers to reflect on their designs and the implementation of their designs.

The third questionnaire on Student peers' experiences with the intervention (see APPENDIX A (A3)) was designed to include items adapted partly, from Agyei (2012) and items from Koh (2013). The questionnaire was used for two purposes: 1) to gain further insights into how the intervention facilitated and enhanced students' understanding of the physics concepts taught from the perspective of the Student peers, and 2) to determine the extent to which the Student peers perceived the PhET simulations-based interventions to be interactive. In all 29 items were constructed and used for these purposes. Fourteen (14) of the items were pre-determined and grouped into 3 sub-scales about the student experiences in relation to their understanding of the PhET simulations-supported lessons. The sub-scales were: 1) Interest—this was aimed at finding out if the lessons engaged the learners' attention; 2) Comprehension— this was used to determine how clear and understanding the lessons were; and 3) Presentation—this was used to determine whether the content was well explained during the delivery of the PhET simulation-based lessons. The remaining 15 items were used to check the level of interactivity achieved with the PhET simulations-based interventions from the perspective of the Student peers. The 15 items were grouped under the five dimensions for meaningful learning with ICT— *Active* (3 items), *Constructive* (3 items), *Authentic* (3 items), *Intentional* (3 items) and *Cooperative* (3 items). This questionnaire was administered twice during Phase 2 of the PDA. Specifically, this questionnaire was given to the same group of Student peers after the second teaching try-out of Design Team A2 and also, after the second teaching try-out of Design Team B2. This was because, the PSSPLs designed by these Design Teams were not the same as they differed in the physics content as well as choice of PhET simulations environment employed.

The focus group discussion/interview was used to collect data after the first and second teaching try-out sessions in Phase 1 and also, after the first teaching try-out session in Phase 2 where both cohort of pre-service teachers taught among themselves. Multiple discussion sessions were planned and directed for the pre-service teachers to reflect on the appropriateness of the designed interventions for the selected topics in physics and the extent to which the interventions promoted interactive teaching. The focus here was on identifying the weaknesses as well as strengths of the interventions and also, providing

suggestions in order to improve the intervention. The focus group discussions were also employed to bring the essence of the training workshop at the beginning of the professional development arrangement (second stage of the study) to bear. The feedbacks in this regard were then used to refine the intervention.

Focus group discussion/interview was also used to collect data after the second teaching try-out sessions of second cohort of pre-service teachers (i.e., Design Team A2 and Design Team B2) in the second study of the implementation and evaluation stage where the pre-service teachers enacted the intervention among the Student peers. Discussions in this respect were purposed to ascertain the usefulness of the interventions in enhancing their understanding of concepts in physics as well as learning outcomes from the perspective of the Student peers. This was aimed at determining the impact of the simulations-based intervention on the Student peers' learning of concepts in physics.

In each of the discussions, I initiated the discussion by posing questions related to the topic taught, how the lesson was delivered and how the simulations environment supported the lesson (see APPENDIX C) for sample questions used). All the focus group discussions were audio-recorded.

Semi-structured interviews were employed after each microteaching try-out session during the implementation and evaluation stage for both Phase 1 and Phase 2. This was aimed at gaining insights into how the pre-service teachers advanced in their development in their design and implementation of the intervention. The instrument (i.e., semi-structured interview guide) was adapted from Agyei (2012). Themes considered in the instrument included: Personal information, Planning and preparation of lesson, During the lesson, Lesson activities, and Post-review of teaching (see APPENDIX B).

Observation was also used in the data collection. In the process, a researcher's logbook was employed to keep vivid and detailed accounts of the activities and events that occurred during the PDA. The pre-service teachers were observed mainly during the design and enactment of the interventions. Areas of interest that were observed by me,

included the appropriateness of the simulations selected for specific topics from the Ghanaian SHS physics curriculum, how the teaching objectives outlined for the designed interventions conformed to the various simulations' environment employed, how the knowledge of subject matter was supported by the simulations for each dimension and the teaching approach adopted.

Lesson artefacts (see APPENDIX D) developed (by the pre-service teachers) were also used as sources of data for the study. These were gathered from the professional development arrangement.

Data were also collected by use of pre- and post- tests (designed by the second cohort of pre-service teachers) in Phase 2 of the evaluation and implementation stage where the participants taught their peers (i.e., Student peers). The tests consisted of the same items on the topics: *Deformation of Solids* (DOS) and *Frictional Force* (FF). These tests were reviewed (by the researcher) and then, conducted before (pre) and immediately after (post) each of the two lessons (DOS by DTA2 and FF by DTB2) was implemented. These two lessons were taught during the second teaching try-out for Phase 2 in which a member of each design team (DTA22 and DTB22 respectively) taught the lessons they designed among nine (9) Student peers after it had been enacted in the first microteaching try-out session. The use of pre-and post-tests in this regard was intended to measure the Student peers' understanding of the physics concepts taught using the interventions designed and also, to ascertain the impact of the ICT (simulations)-based intervention.

These sources of data were employed to ensure triangulation in order to explain as well as gain in-depth understanding of how the pre-service teachers developed their competencies for integrating simulations in their teaching practices. See APPENDIX D (D4 and D5) for the test items constructed by DTA2 and DTB2 respectively.

The data collection instruments as discussed in this section were used to address mainly research question two (RQ2) and research question three (RQ3) where necessary. It is important to mention that none of these instruments were used for RQ1 as that was

addressed solely based on the literature reviewed in coming up with the initial design guidelines as mentioned earlier in section 3.2.1. Table 3.2 gives a summary of the data collection methods discussed herein and their links to addressing RQ2 and RQ3.

*Table 3.2: Summary of data collection methods/instruments and their respective linkages to research questions two and three.*

<b>Research question</b>	<b>Data collection methods/instruments</b>
RQ2	<ul style="list-style-type: none"> <li>• Focus group interviews</li> <li>• Semi-structured interviews</li> <li>• Lesson artefacts (e.g., lesson plan documents, activity sheets and presentation slides)</li> <li>• Observation (researchers' logbook)</li> <li>• Questionnaires (Five-dimension survey and Student peers' questionnaire)</li> </ul>
RQ3	<ul style="list-style-type: none"> <li>• Focus group interviews</li> <li>• Semi-structured interviews</li> <li>• Lesson artefacts (e.g., lesson plan documents, activity sheets and presentation slides)</li> <li>• Observation (researchers' logbook)</li> <li>• Questionnaires (TPACK self-assessment pre-post) survey and Student peers' questionnaire)</li> <li>• Pre- and post- tests (scores and written responses)</li> </ul>

### **3.8. Data analysis**

By employing a DBR approach with an explanatory type of case study design, a combination of qualitative and quantitative methods of analysis were employed. Descriptive statistics specifically, means and standard deviations were used to analyse the quantitative data from the TPACK survey, Five-dimensions survey, Student peers' questionnaire and the pre- and post-tests. The analytical instrument used was the Statistical Package for Social Sciences (SPSS). Possible answers to items on the

TPACK, Five-dimension and the Student peers' questionnaires were all scaled to range from strongly disagree (1) to strongly agree (5). An average of 3 and above indicated a positive favourable opinion while below 3 indicated a negative opinion of the pre-service teachers' responses for the TPACK and Five-dimension questionnaires. However, for the Student peers' questionnaire, a mean score of 3 and above indicated a positive favourable opinion while a mean score below 3 indicated a negative opinion of the Student peers' response.

The tests (i.e., pre and post) were made up of five (5) items for each lesson. They were scored out of 10 and scaled down to 5. A mean score of 3 and above was considered as a positive and favourable score while a mean score below 3 was considered as an unfavourable outcome.

The observation data recorded in the researcher's logbook was in the form of a text while data from the semi-structured interview and the focus group discussion were transcribed from audio to text. The observation, semi-structured interview, and focus group discussion data were all analysed through data reduction technique (Miles & Huberman 1994) which was accomplished by identifying themes as well as patterns in line with the conceptual framework. These themes were then grouped into the pre-service teachers' perspectives as they appeared in the semi-structured interviews and discussions in relation to the research questions. The pre-service teachers' viewpoints which could not be group under the research questions were not left out; as they were considered as vital information for immense understanding of the developmental process. The groupings were explored for the purpose of refinement, coding and recoding, and identification of contradictory views. The final groupings of the themes were then interpreted. Document analysis was also employed to analyse and give meanings to the: 1) Student peers' written responses to items on the pre-and post-tests document and 2) word-based data gathered from the pre-service teachers' simulations-supported lesson artefacts (i.e., activity sheets, lesson plans and presentation slides) with keen interest in the designed lesson activities that were developed by the pre-service teachers based on the selected PhET simulations.

Quantitative evidence was presented using tables and graphs while themes, Verbatim quotations, non-verbal expressions, pictures as well as excerpts from the qualitative data sources were used where necessary to present evidence.

### **3.9. Validity and reliability**

This section is presented to establish how the research proceedings adopted for the current study were conducted in a manner that can be best described as professional, precise, systematic, and transparent.

For the quantitative instruments, the test items were validated by three experts who were in the areas of Curriculum design and Instructional technology among which were my supervisors. In addition, the TPACK survey has been reported by Schmidt et al. (2009a), to have a good internal consistency with a Cronbach's alpha reliability estimate ranging from 0.75 to 0.93 and a construct validity score of 7.88 (Schmidt et al. 2009b) for five out of the seven constructs of the TPACK framework. Agyei (2012) also reported internal consistency with Cronbach's alpha reliability ranging from 0.70 to 0.89 for the TPACK survey in a similar context as the current study. Based on these results, the TPACK instrument was considered valid and reliable. The Five-dimension survey was also considered reliable based on reports from Koh's (2013) which indicated Cohen's kappa of at least 0.80 for all the five dimensions. (*Active: 0.93, Constructive: 0.93, Intentional: 0.89, Authentic: 0.85, Cooperative: 0.92*).

As the current study was largely qualitative, trustworthiness of the study was ensured based on Lincoln and Guba's (1985:80) criteria of "credibility", "transferability", "dependability" and "confirmability".

#### **3.9.1. Credibility**

Credibility was enforced through Shenton's (2004) propositions; namely: triangulation, tactics for ensuring honesty in informants, iterative questioning, member checks, and my

reflection commentary by use of the researcher's logbook. A combination of qualitative and quantitative evidence was employed at different stages of the study to facilitate in-depth understanding of the process of development in the pre-service teachers' TPACK sought in the study. Thus, multiple data sources and analysis procedures adopted in the study were careful measures taken to ascertain triangulation (Agyei, 2012).

To ensure honesty by the informants (participants), the participants were given the freedom to refuse or accept to participate in the study. This was a way of ensuring that only willing pre-service teachers participated in the study. The participants were encouraged to be frank and objective during the professional development arrangement. I endeavored to establish rapport with the participant in a way that made them feel comfortable and appreciated.

Iterative questions were used as a strategy especially during the interview sessions of the study to extract similar data for 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.

For member checks, transcribed dialogues were given to informants to cross-check and confirm that their words during the focus group discussion and interviews were exactly as they intended at the time of the interview sessions, and accurately captured by me.

The researcher's commentary was the last strategy adopted for ensuring credibility through my logbook. This was the method by which I consciously tracked the developmental process of the study. This provided the premise for me to evaluate the study as it progressed. This was achieved by taking field notes at every stage from the design to the implementation stage.

### **3.9.2. Transferability**

According to Lincoln and Guba (1985), the underlying idea for transferability is for the researcher conducting a study to make available to readers (future researchers), detailed description of the phenomenon under study to enable them make sound judgements that

could be applied in other contexts. As the study was time- and context-bound, the findings could not be generalised beyond its scope, however, I provided sufficiently vivid descriptions of the context, methodology, and findings of the study to allow readers (future researchers) transfer the details of the study to their own experience.

### **3.9.3. Dependability**

Triangulation of the multiple sources of data, repeated observation of pre-service teachers' lessons, and the code-recode technique used in the data analysis were all key to achieving the dependability criterion. More importantly, the limitations in one data collection technique was resolved by the strength of another. In addition, two of my supervisors checked and verified for the consistency of the methods and procedures used in conducting the study to ensure that an acceptable process of inquiry was followed. They also dutifully reviewed the research reports throughout the study. The feedbacks were necessary for shaping and improving the reports into the required standard. The processes within the study were described in detail to facilitate further research work. Two experts in the areas of instructional design, physics education and ICT integration appraised the exemplary ICT interventions to ensure its practicability and improve its validity. Thus, their views and suggestions were deemed relevant for improving the quality of the exemplary ICT interventions.

### **3.9.4. Confirmability**

Shenton (2004:72) explained confirmability as a researchers' "comparable concern to objectivity" in qualitative research. From Guba (1981) perspective, confirmability is for a research to be deliberately impartial in relation to the data and how interpretations are given based on the analysis produced from the research. Thus, in this study, confirmability was ensured by triangulation—to minimise researcher bias; giving credit where due by acknowledging the ideas of other researchers that informed the decisions made as well as the methods employed in executing the study; and ensuring that the findings of the study reflected the responses of the participants (pre-service teachers) and not my personal impressions.

### **3.10. Limitations of the study**

A case study (explanatory) design was employed by use of multiple data evidence in order to explain how the pre-service physics teachers developed competencies in integrating ICT in teaching physics mediated by simulations. Though each method adopted for data collection has its own inherent errors and limitations which cumulatively may affect few results and conclusions drawn, the different approaches were complementary when triangulated; thereby improving confidence in the findings. The survey method for example, was associated with issues such as clarity of items. To resolve the issue of clarity, my presence was ensured during the answering of the questionnaire. By this precaution, the respondents were given clarification on the items (in the questionnaire) that they did not understand. Also, with the survey method, the tendency for participants to overestimate their competencies was an issue of concern. This was resolved by use of observation as well as the document analysis of their lesson artefacts which helped in getting a clear picture of what their competencies were before and after the implementation of the ICT intervention.

The case study design allowed for only limited number of participants to be used in the study. Thus, generalising the results to a larger population is not possible. The study however adopted an explanatory type of case study in order to make analytical generalisations that are important for the formulation of design guidelines. The iterative process as afforded by the DBR was upheld to ensure that explanations given in the study were “independent of any methodological biases” (Harder, 2012:3). Data collected from both quantitative and qualitative evidence were also triangulated to strengthen the veracity of any explanation given (Yin, 2003).

In this study, I assumed a dual role as the researcher and the facilitator during the initial training workshop. I observed the pre-service teachers during their enactment of the interventions they developed and I was also involved in the focus group discussion sessions as I needed to take notes as well as record the proceedings to that effect. Thus, the issue of researcher biases was inevitable. Reflexivity and the use of multiple sources

of data therefore provided the basis for resolving this issue through triangulation.

The study was context-bound in that, pre-service teachers considered for the study were selected from only one higher education institution in Ghana (University of Cape Coast). This could limit transfer of the study to other higher education institutions. The pre-service teachers had physics as their major teaching subject. This placed a limitation on the extent to which data as well as outcomes of the study could be applied to other science subjects such as biology and chemistry and its application.

### **3.11. Summary of the chapter**

Methods used for conducting the study has been explained and discussed in this chapter. Interpretivism paradigm was the philosophical basis on which the study was situated, therefore the study was largely qualitative. By the interpretivism stance, the study was driven by an inter-subjective approach. The interpretivism ideologies were considered as an essential ingredient for developing knowledge and skills with emphasis on meanings and understandings of the processes involved. Hence, the study adopted the ideologies of a qualitative research with a Design-Based Research approach and a case study design which is explanatory in nature using qualitative as well as quantitative evidence to track and understand the process of development of the pre-service teachers as they integrated simulations as an interactive ICT tool for teaching physics in a learner-centred constructivist manner.

The next chapter presents the results of the study.

## **4. CHAPTER 4: PRESENTATION OF FINDINGS**

### **4.0. Introduction**

The current chapter presents the findings from the multiple source of data collected during the professional development arrangement for all two phases of the study. Data were collected over a stretch period of four weeks for Phase 1 of the study—from the last week of May, 2017 to the third week of June, 2017, and seven weeks for Phase 2 of the study — from the second week of September, 2017 to the first week of November, 2017. Within this time frame, data collection was subjected to the convenient times of the participants. The results of the study are presented in relation to the research questions considered for the study using tables, graphs, themes as well as excerpts from the qualitative data where necessary. Thus, both qualitative and quantitative evidence were used where appropriate to address the research questions. This was done to ensure triangulation of the data.

Before presenting the results of the study, I give an overview of the study in terms of the purpose as well as the research methodology. The background of the participants is also highlighted with emphasis on their roles in the study.

The overall purpose of this study was to track and understand the process of development of pre-service teachers' knowledge and skills for integrating ICT (simulations) in the teaching and learning of high school physics in Ghana, using Physics Education Technology (PhET) simulations as an interactive ICT tool. It is important to mention that in this chapter the words: “PhETs”, “simulation(s)” or “sims” are all taken to mean PhET simulations.

The study used a Design-Based Research (DBR) approach with an explanatory case study design and employed both qualitative and quantitative evidence of data collection and analysis to track and understand the process of development of the pre-service teachers as they developed and enacted PhET simulations-supported physics lessons (PSSPLs) in a learner-centered constructivist manner. The quantitative data was

analysed by use of descriptive statistics (i.e., means and standard deviation) while for the qualitative, transcribed interviews and focus group discussions data were analysed by identifying themes as well as patterns. Document analysis was also employed to analyse and give meanings to the word-based data gathered from the pre-service teachers' simulation-supported lesson artefacts (i.e., Activity sheets, lesson plans and presentation slides) with keen interest in the designed lesson activities that were developed by the pre-service teachers based on the PhET simulation environments chosen for the design of the intervention.

#### **4.1. Background of the participants of the study**

The total number of pre-service teachers that participated in the study to design and develop the ICT (simulations)-based intervention was Eight (8). Four participated in the Phase 1 of the study and four participated in the Phase 2. The four who participated in the first phase were 4<sup>th</sup> year students who were enrolled in the Science Education teacher preparation programme at the University of Cape Coast (UCC) for the 2016/2017 academic year while those who participated in the second phase were in their 3<sup>rd</sup> year of the same programme at UCC for the 2017/2018 academic year. At each phase, the pre-service teachers were grouped into two Design Teams (DTs) (i.e., Design Team A and Design Team B) of two pre-service teachers each. Thus, depending on the phase of the study, the Design Teams were named: DTA1, DTB1, DTA2, and DTB2—implying that DTA1 and DTB1 participated in the first phase of the study while DTA2 and DTB2 took part in the second phase of the study. The pre-service teachers in DTA1, DTB1, DTA2, and DTB2 were designated DTA11 and DTA12; DTB11 and DTB12; DTA21 and DTA22; and DTB21 and DTB22 respectively. The pre-service teachers were identified with the last number attached to each designation since it represented the specific microteaching try-out session in which a particular participant taught with the intervention. For example, the last number (i.e., 1) attached to the designation DTA11 is an indication that, that particular pre-service teacher enacted his teams' simulation-based lesson during the first microteaching try-out session. The same applies to the rest of the designations.

Another group of participants for the present study were Level 200 (i.e., 2<sup>nd</sup> year) pre-service teachers who were enrolled in the Science Education teacher preparation programme at UCC for the 2017/2018 academic year. These pre-service teachers only participated as learners (to mimic senior high school science students) during second microteaching try-out sessions of Design Teams DTA2 and DTB2 in the second phase of the current study. They were designated in this study as Student peers.

## **4.2. Results of the study**

The results are organised and presented according to the three research questions considered for achieving the overall goal of the study. With the exception of research question one (RQ1), all other research questions (i.e., research question two (RQ2) and research question three (RQ3)) were addressed using both quantitative and qualitative evidence for triangulation purposes. In the sections that follow, the findings of the study are presented and discussed to address each research question.

### **4.2.1. Research question one (RQ1)**

What ICT interventions can be designed to fit the realities in the senior high school (SHS) classroom in a manner that makes the teaching of physics interactive in Ghana?

To address RQ1, the first two drafts of ICT (simulation)-based intervention designed and enacted by the researcher to serve as an exemplary material for the pre-service teachers were examined to ascertain the kind of ICT (simulations)-based intervention that best fit the realities in the Ghanaian SHS physics classrooms for interactive teaching of high school physics. The interactive features of the intervention were therefore deemed important in this study for preparing the participating pre-service teachers to effectively design and implement ICT (PhET simulations)-based lessons for the enhancement of students learning outcomes. For this purpose, the first stage (i.e., the design stage) considered for the DBR approach served as the gateway to answering RQ1; whereby, literature reviewed in this study was used as a lens to identify the appropriate and interactive features to consider for the development and design of the two exemplary ICT

(simulation)-based interventions. This was essential as it formed the basis for the formulation of the initial design guidelines that governed the development and design of the two exemplary interventions in this study. This was aimed at preparing the pre-service teachers to: 1) collectively design their own ICT-based interventions based on their experience with the exemplary material and consequently, inform their use of ICT (simulations) to teach high school physics in an interactive manner.

The initial design guidelines that governed the development of the two exemplary ICT (simulation)-based interventions constituted the following; the use of:

- an ICT tool that is readily available, user friendly, sustainable in the context in which it is to be used and can support interactive teaching of physics for meaningful learning outcomes (Rehn et al., 2013; Wieman & Perkins, 2005).
- framework(s) to: 1) ground the type of knowledge required for ICT integration into the teaching of physics and 2) explicitly define interactive teaching with ICT in a way that situates the learner as the focus in the physics classroom (Howland et al., 2012; Mishra & Koehler, 2006; Voogt & McKenney, 2016).
- activity-oriented worksheets that employ the affordances of a selected ICT tool in an exploratory self-directed inquiry or a demonstrative form of inquiry to facilitate learner's conceptual understanding of the subject matter (physics) (Agyei, 2012).
- collaborative approach to learning for the enforcement of team work capabilities in learners (Jonassen et al., 2008; Vygotsky, 1978).

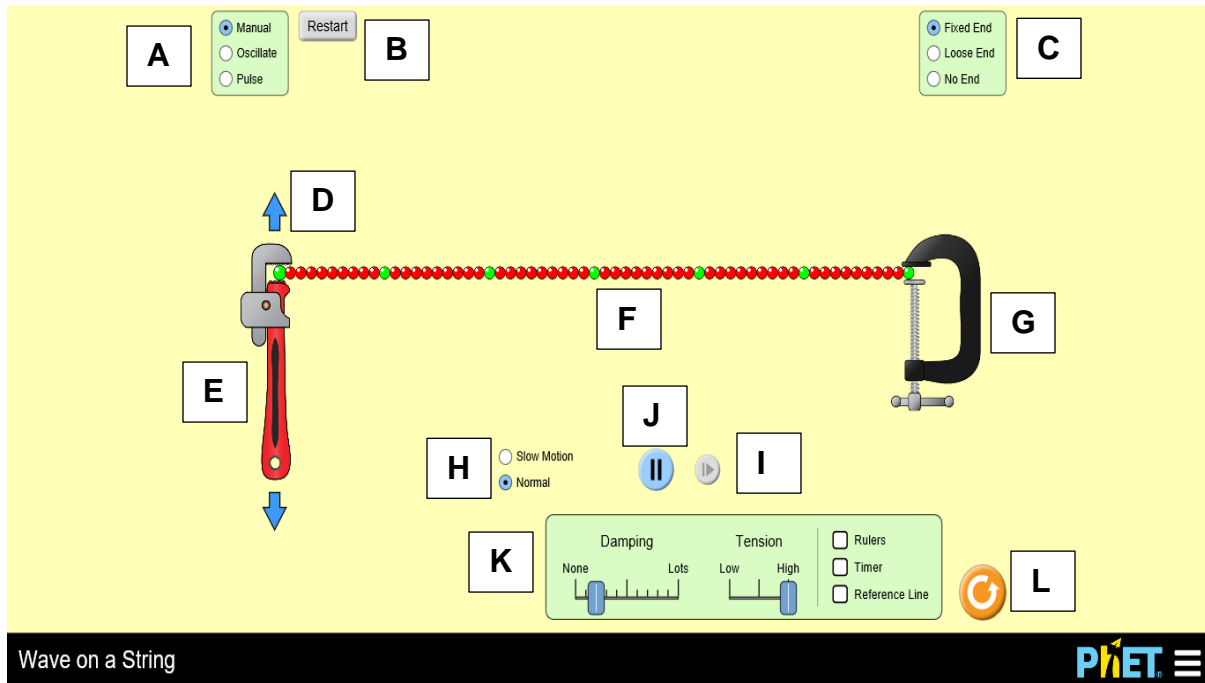
The aforementioned initial design guidelines governed the design of the exemplary interventions (see APPENDIX D (D1 and D2) for the study. Informed by the initial design guidelines, the incorporation of features such as PhET simulation environment, Interactive learning objectives (ILOs), Technological pedagogical content knowledge and the five dimensions for meaningful learning with ICT (TPACK-5DML) element, Activity sheet element and Collaborative learning approach feature characterised the exemplary ICT intervention. In the sections that follow, each of these features are discussed.

#### 4.2.1.1. Physics Education Technology simulations (PhETs)

PhET simulation was used as the interactive ICT tool for the design of the two exemplary interventions in this study because it was found to be readily available as it is free and can be downloaded from the PhET website (<http://phet.colorado.edu>) to be used offline on a computer. This makes the PhETs suitable, accessible and sustainable for the Ghanaian SHS classroom context. It was also revealed to be user friendly mainly because of its different manipulative and interactive interface that allows a user or a learner to easily explore and interact with it in order to discover and learn about its content-driven affordances for the representation of a subject matter of choice.

In the next section, I give an overview of each of the two PhET simulation environments used in the design of the exemplary intervention. This is intended to bring to light their respective affordances in order to show how they informed the design of the two exemplary interventions.

The PhET simulation environment, entitled: *Wave on a String* (denoted as *WS*) was used in the design and development of the lesson artefacts for the lesson on Wave motion which produced the exemplary intervention 1. Figure 4.1 shows the unexplored first interface of the *WS* PhET.



**Figure 4.1: Wave on a String PhET simulation environment.**

I added the labels **A** to **L** (in Figure 4.1) to the simulation interface just for the purpose of making references to its interactive features in order to make it easy for explaining their affordances. Each feature of the simulation environment is designed for a specific purpose for effective representation of the subject matter. For example, feature **A** is a multiple purpose tab designed to facilitate the exploration of the simulation in three different modes using the options *Manual*, *Oscillate*, and *Pulse*. The selection of the *Manual* option gives the interactive interface as shown in Figure 4.1 —this provides an interactive atmosphere for waves to be generated manually by use of a wrench (i.e., feature **E**). The wrench is designed such that it can be moved up and down (as indicated by the blue up and down arrows, feature **D**) to generate a wave profile. The feature **F** represents the medium of propagation through which energy can be transferred. As depicted in the simulation environment, the medium of propagation is a string with its particles represented by the red and green balls. The refresh button (labelled **L**) is designed to bring the simulation environment to its initial interface during exploration when necessary. The feature labelled **G** in the simulation environment mimics a G-clamp

and it is used to provide a fixed end to the string when the *Fixed End* option is selected from tab **C** as shown in Figure 4.1. A wriggle of the wrench at the left end of the string generates a wave down the length of the string by way of supplying energy to the string. The feature **H** provides the learner/user with the option to slow down the simulation feedbacks during exploration or to allow the simulation to give feedbacks using its own speed. Features **J** and **I** allow for the simulation environment, when in operation to be paused and forwarded respectively when necessary. **K** is also a multiple purpose tab with different features with different functions for the representation of the subject matter. Embedded in the tab **K** is a *Damping slider* with ruler markings from *none* to *lots* which, when moved beyond the *none* mark towards *the lots* is designed for the purpose of introducing a dissipative force (i.e., friction between the oscillating particles of the string and the particles of air) into the oscillating system that the *WS* simulation mimics with the string. This causes the *Amplitude* of the string when oscillating to decrease with time as energy is lost to the surroundings in the simulation environment. Another element in the tab **K**, is the *Tension* slider with ruler markings from *Low* to *High*. This is designed to regulate the force exerted by the string when it is being pulled by either the wrench manually or the oscillator when the simulation environment is set to the oscillating mode (using the *Oscillate* option). An increase in the tension beyond the *Low* mark (i.e., moving the *Tension* slider towards the *High* mark on the slider) increases the speed of the wave generated. Other elements in the tab **K** feature of the *WS* simulation interface include the options of: *Rulers*—which, when checked, adds vertically and horizontally designed rulers to the simulation environment for taking readings in units of centimeters; *Timer*—when checked, adds a timer to the simulation interface for recording the period of oscillation of the wave generated in seconds; and *Reference line*—when checked provides the user with a dotted line to assist in taking accurate readings using the ruler feature. The options *Loose End* and *No End* as indicated in the tab **C** provide loose end for the string by use of a ring on a pole when the *Loose End* option is selected and no end for the string when the *No End* option is selected respectively.

The interactive features of the *WS* PhET simulation as described informed the topic: *Wave motion* as well as the specific learning objectives (see Excerpt 4.1) set for the

implementation of the exemplary intervention 1. With a consideration for time and the realities in the Ghanaian SHS classroom, three specific objectives were set for the implementation of the exemplary materials for exemplary intervention 1. These objectives were however adapted from the GPC4SHS to ensure that the intervention aligned with the stipulations of the GPC4SHS in relation to the physics content.

<b>Specific Objectives</b>	<p>At the end of the lesson, students should be able to:</p> <ul style="list-style-type: none"> <li>▪ explain waves as a transfer of energy and not matter.</li> <li>▪ describe measurable waves properties such as amplitude and wavelength</li> <li>▪ describe how amplitude and wavelength affect waves.</li> </ul>
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**Excerpt 4.1: Aspect of lesson plan document showing the learning objectives set for the implementation of the exemplary intervention 1 by use of the *Wave on a String* PhET simulation environment.**

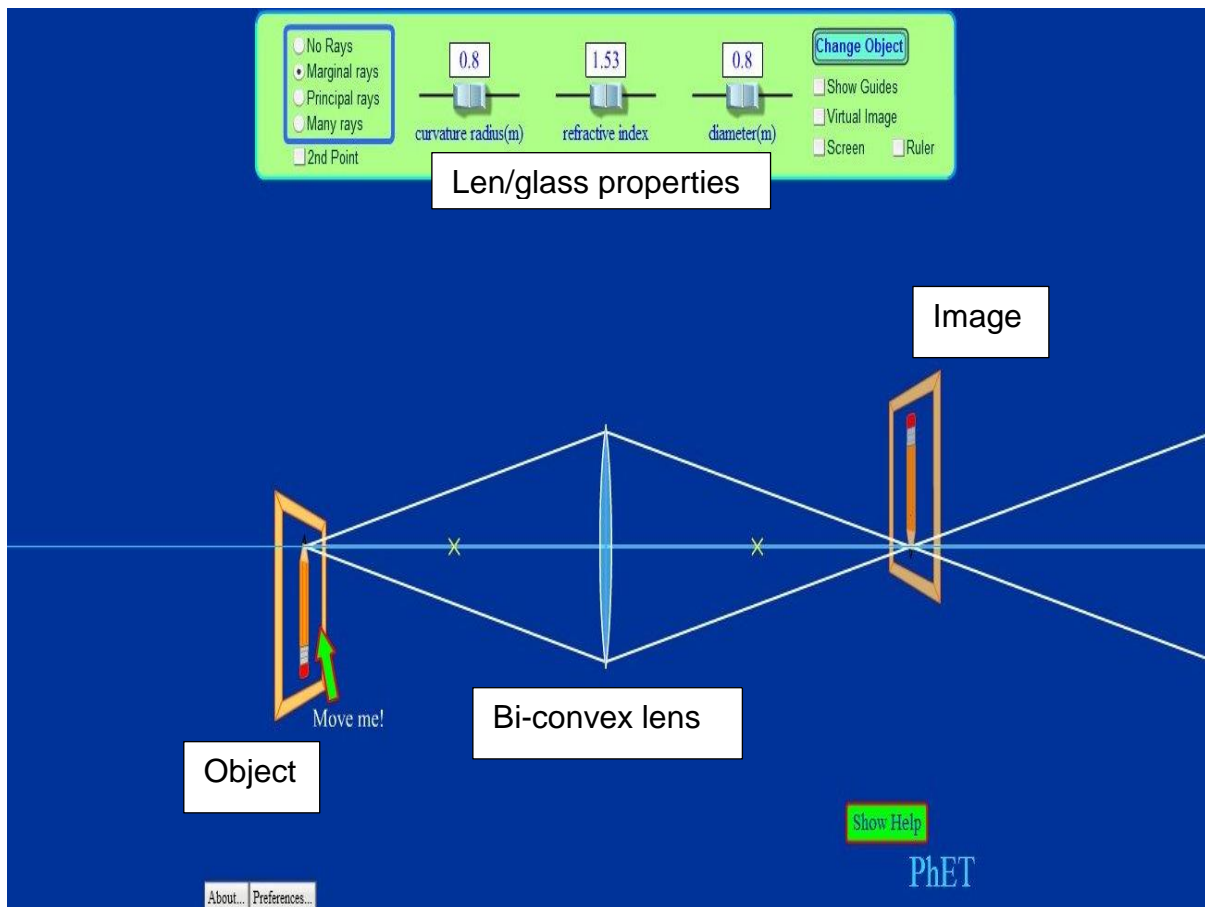
In particular, the *Oscillate* option (in tab **A**) of the *WS* simulation environment was considered useful in achieving the learning goals with the other supporting features of the simulation interface. This is because when selected, it provides an authentic interactive platform for measurable properties of a wave such as *Amplitude*, *Frequency* and even *Wavelength* to be practically explained and to appreciate the relationship that exist between them.

The second PhET simulation environment employed for the design of the exemplary intervention 2 is entitled: *Geometric Optics* (denoted as *GO*). It also has interactive features (i.e., tabs, menus, sliders etc as indicated in Figure 4.2.) as that observed in the *WS* simulation environment. However, it is different in terms of the physics concepts it mimics. For example in this study, it was used in the design of the exemplary intervention 2 for achieving two learning goals under the topic: *Formation of images by a bi-convex thin lens* in order to help learners:

1. describe the characteristics of the image formed by a converging lens at different object positions and,

2. describe how the curvature radius of a converging lens affects the nature of images formed.

To achieve these learning goals, its interactive interface provided an avenue for knowledge construction as well as a stimulating learning ground for learners to put to use not only their prior knowledge about converging lenses, but also their personal experiences with lenses in their every day lives in order to connect their understanding of the physics concept to the real-world.



**Figure 4.2: Geometric Optics PhET simulation environment (unexplored).**

As can be observed from Figure 4.2, the GO simulation uses a pencil in the square frame on the left of the bi-convex lens to represent an object while that on the right side of the bi-convex lens represents the corresponding imaged formed at an object distance twice

that of the focal length of the lens. With its interactive features, the object can be placed at different object distances to describe the characteristics of the corresponding image formed. This informed the first learning goal that was set for the exemplary intervention 2. It can also be observed from the simulation interface that the sliders namely: *curvature radius*, *refractive index*, and *diameter* are all properties of the lens and thus, can be varied by use of their sliders at different intervals within the simulation’s limit to determine their influence on the nature of images formed at specific object distances. This formed the basis for the second learning goal set.

#### 4.2.1.2. Interactive learning objective (s) (ILOs)

Owing to the affordances of the PhET simulations, an “interactive learning objective” was incorporated in the ICT intervention design in support of the “specific learning objectives” as defined in the GPC4SHS. The ILO was purposed to bring to focus the different ways by which the affordances of a selected PhET simulation could be used to represent the subject matter. Examples of ILO feature in the exemplary interventions 1 and 2 are shown in Excerpts 4.2 and 4.3 respectively.

<p><b>Interactive learning Objectives</b></p>	<p>At the end of the lesson, students should be able to use Physics Education technology (PhET) simulation entitled: <i>waves-on-a-string</i> guided by exploratory activities on waves, to</p> <ul style="list-style-type: none"> <li>▪ observe how energy is transferred when a string is wriggled at one end,</li> <li>▪ manipulate the various elements of the simulation to identify measurable properties of waves and</li> <li>▪ compare how the nature of the wave generated changes as one property is varied whilst, others are kept constant.</li> </ul>
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**Excerpt 4.2: ILO stated in the lesson plan document for the exemplary intervention1 for the topic: Wave motion.**

<b>Interactive learning Objectives</b>	<p>At the end of the lesson, students will be able to use and explore the PhET simulation environment to:</p> <ul style="list-style-type: none"> <li>▪ observe how a change in the position of an object placed before a converging lens determines: <ul style="list-style-type: none"> <li>➤ the location of the image formed.</li> <li>➤ the nature of the image formed.</li> </ul> </li> <li>▪ determine how varying values of the curvature radius affects the kind of image formed by a converging lens at constant lens diameter as well as refractive index.</li> </ul>
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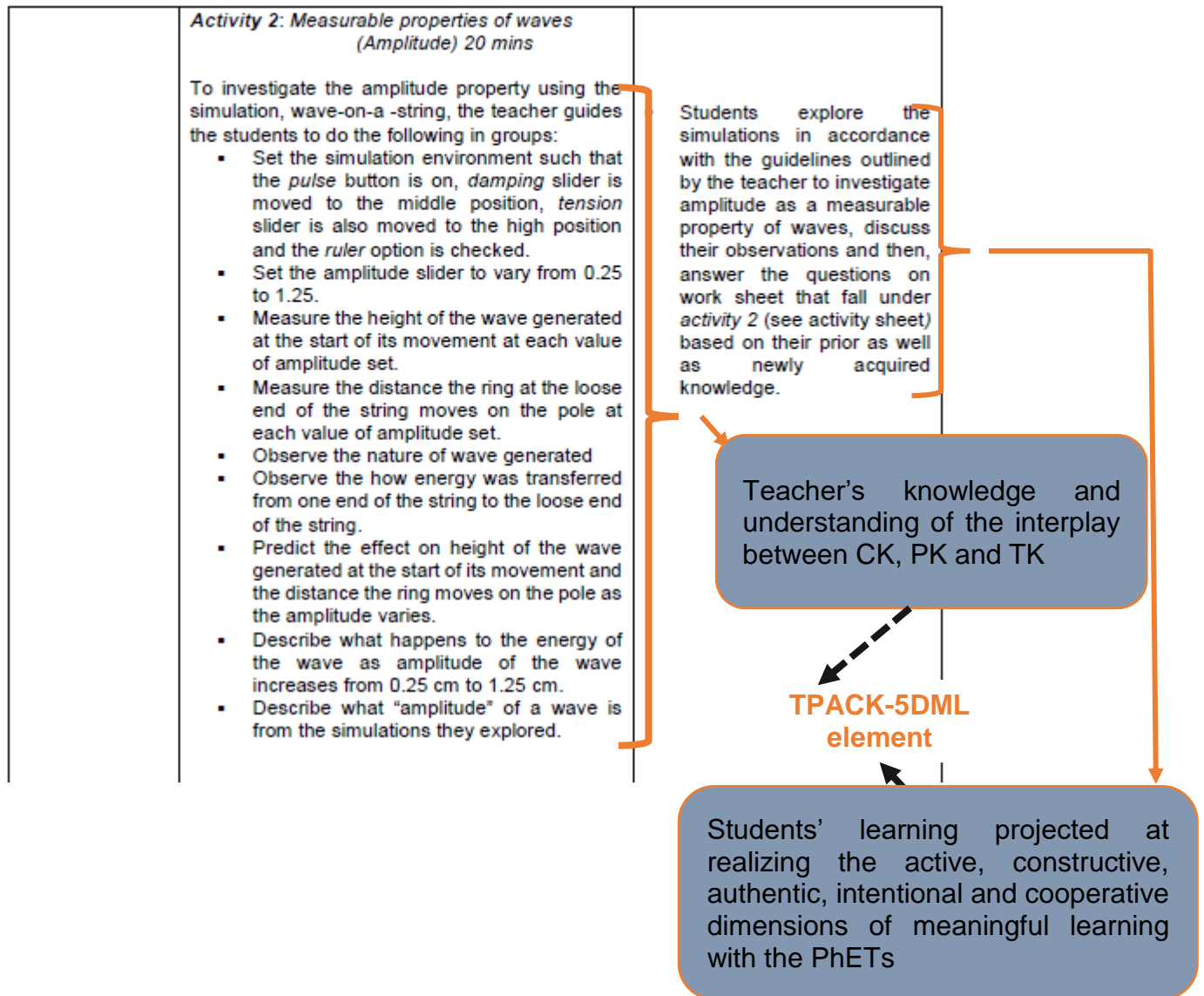
**Excerpt 4.3: ILOs stated in the lesson plan document for the exemplary intervention 2 for the topic: Formation of images by a converging lens.**

As can be observed from Excerpts 4.2 and 4.3, the ILOs feature in the lesson plan documents shows explicitly how the selected PhET simulation environment is to be used in achieving the specific learning objectives. Also, by the ILOs feature, the teacher’s understanding of the affordances of PhET simulation environment is put into practice and directed at projecting an activity-based atmosphere for meaning making of the subject matter. This provides the platform for establishing the type of knowledge required for ICT (simulations) integration into the teaching of physics and also, defining explicitly, interactive teaching with ICT (simulations) in order to make the learner the focus in the physics classroom.

**4.2.1.3. Technological pedagogical content knowledge and the five dimensions for meaningful learning with ICT (TPACK-5DML) element**

The TPACK (i.e., Technological pedagogical and content knowledge as proposed by Mishra and Koehler (2006))-5DML(i.e., Five dimensions for meaningful learning with ICT by Howland et al. (2012) as adapted by Koh (2013)) element (see Figure 4.3) in the exemplary ICT intervention developed in this study was envisaged as the “built-in” competency trademark of the teacher in using ICT (specifically, PhET simulations) for the creation of an interactive learner-centred teaching and learning atmosphere for teaching high school physics. In this regard, TPACK-5DML element formed the core of the exemplary ICT intervention that was designed to fit the Ghanaian SHS physics classroom

because it had inherent elements that reflected the teacher’s “knowledge and understanding of the interplay between content knowledge (CK), pedagogical knowledge (PK) and technology knowledge (TK)” (Agyei 2012:71) that is needed to drive the interactive prospect with the PhET simulation environment for the purpose of stimulating learners to be active, constructive, authentic, intentional, and cooperative in a constructivist teaching and learning atmosphere.



**Figure 4.3: Illustration of the TPACK-5DML element based on the activities designed under Activity 2 of the exemplary intervention 1.**

The TPACK-5DML element of the exemplary ICT intervention was incorporated in the design of the PhET simulations-based activities and hence, reflected in the lesson plan document as shown in Figure 4.3. Figure 4.3 is an example of the TPACK-5DML element as incorporated in the lesson plan document of the exemplary intervention 1.

#### **4.2.1.4. Activity sheet element**

The exemplary ICT (simulations) intervention also had activity sheets designed as part of the lesson artefacts. The addition of the activity sheet element to the ICT intervention was deemed necessary because it provides the means to actively engage learners to be initiative and also, to take full responsibility for their learning of the subject matter. The activities were designed by use of the PhET simulation environment to enforce two types of inquiry: 1) an exploratory self-directed form of inquiry, and 2) a demonstrative form of inquiry. With all the two forms of inquiry, the activities for the exemplary interventions were developed to make the learner the focus of the instructional process—with their prior knowledge of the subject matter and personal experiences with the simulation environment serving as the building block for the construction of new knowledge. It is important to mention that, the exemplary intervention 1 was exploratory in nature with emphasis on a Ghanaian classroom situation where both the teacher and students (learners) have access to the computer while that of the exemplary intervention 2 was demonstrative in nature. The demonstrative and exploratory forms of inquiries were considered for the purpose of providing interventions that are designed to reflect the specific context of a Ghanaian high school physics classroom where two scenarios are possible: 1) where only a computer is available to a teacher due to lack of computer resources, and 2) where both teacher and students have access to computers respectively. The use of both forms of inquiry in the design of the activities were aimed at maximising the potentials of the PhETs to facilitate ownership on the part of the learners through team work for enhancement of learners understanding of concepts in physics.

The activity sheet element of the intervention comprised three components: Introductory activity/activities, Main activities and Take-home assignment (s) (see APPENDIX D: D1

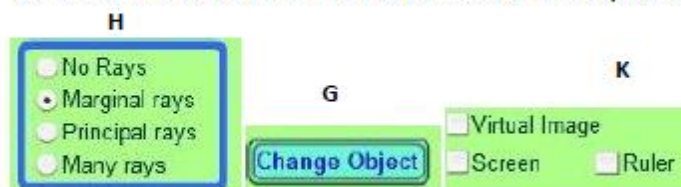
and D2). The introductory activity was designed in the form of either a test to engage learners' prior knowledge about the subject matter; this was purposed to prepare them for the concepts to be discussed in the lesson— as was the case for the exemplary intervention 1 (see Excerpt 4.4) or in the form of exploratory activity to stimulate learners to discover the affordances of the interactive features of the simulation environment by themselves based on their prior knowledge— as was the case for exemplary intervention 2 (see Excerpt 4.5).

#### Introductory Activity (pre- and post-tests)

1. Indicate whether the following statements are true or false
  - a. A wave is a disturbance that carries matter from one point to another in a medium. True/False?
  - b. A wave always move through space. True/ False?
  
2. The following statements describe the various parts of a wave. Indicated in the blank space, the part of a wave that each statement best describes.
  - a. The original position of the medium of propagation of a wave  
.....
  - b. The highest point of the wave above line of origin.....
  - c. The distance between two consecutive lowest points of a wave below the line of origin; .....
  - d. The distance from the line of origin to the highest point of a wave above the line of origin .....
  
3. Draw a wave and identify the parts indicated in a, b, c, and d in question 2 above.

#### Excerpt 4.4: Test items for introductory activity for exemplary intervention 1.

2. By observing the simulation environment, predict the implication of each of the elements indicated below to the lens action as depicted by the simulation.



H: .....

G: .....

K: .....

**Excerpt 4.5: Sample introductory activity designed for exemplary intervention 2.**

As can be observed from Excerpt 4.4, all the test items for the introductory activity (for exemplary intervention 1) were conceptual questions designed for the purpose of engaging learners' previous knowledge about the physics concept: *Wave motion*. The introductory (exploratory) activity for the exemplary intervention 2 as shown in Excerpt 4.5 was intended to help learners to make sense of the interactive features of the GO PhET simulation based on their prior knowledge of thin lenses and their experiences with the simulation interface as they explored its features.

The main activities for both exemplary interventions (see APPENDIX D: D1 and D2) were designed based on the selected PhETs for the design of the exemplary interventions and also, made to align with the specific learning objectives as well as the interactive learning objectives set. A combination of different types of guidance were used to help learners in their prospects with the main activities. These were ensured by the use of instructions, snapshots from the simulation environment, tables, and follow-up questions. The follow-up questions in particular, served as a supplement to the various activities that were designed based on the affordances of the PhET simulations (i.e., *WS* and *GO*) adopted. Thus, under every activity considered for the exemplary interventions with respect to the topics: *Wave motion* and *Formation of images by a bi-convex thin lens*, there were guiding (follow-up) questions. These questions were designed to be open, conceptual, and

application-driven with the intent to provoke learners' conceptual understanding of key concepts covered in the designed lesson. Though, these questions were designed to be simulation-informed, they were not simulation-focused as the purpose for the use of the simulation was not for learners to acquire skills on its use only, but also to help students achieve their learning goals. The follow-up questions were crucial for the facilitation of students' sense making and observation capabilities and were designed to provide a platform for students to make candid deductions from the information they had gathered as a result of their interaction with the simulation environment used in the design of the exemplary intervention.

The main activities were also designed to project the *Active*, *Constructive*, *Authentic*, *Intentional*, and *Cooperative* dimensions for meaningful learning. As operationalised in the current study (see Chapter 2), the activities were designed by use of the PhET simulations to: engage learners in learning the subject matter (*Active*); reflect upon the subject matter and express their ideas and meaning beyond what is presented them (*Constructive*); connect their personal experiences to the real-world (authentic); engage learners in diagnosis, evaluation, and improvement of the learning gap (*Intentional*); and engage learners in group work for divergent knowledge expressions (*Cooperative*). Example of the projection of these dimensions in the ICT intervention is shown in Excerpt 4.6 using Activity 2 of the exemplary intervention 2 for illustrations.

**Activity 2:** lens property—*Curvature radius*

Intentional

This activity is purposed to investigate the effect of the curvature radius on the nature of image formed at different positions of the object using the simulation—*Geometric Optics*.

Based on your observations of the demonstrations exercises using the simulation, discuss in groups and provide answers to the following questions:

1. Describe how the bi-convex lens used in the simulation behaves as the curvature radius slider is altered from one value to another.

Cooperative

Constructive

.....  
.....

Constructive

2. In simple terms, define curvature radius based on the dynamics in the simulation environment as the *curvature radius* slider is altered.

.....  
.....

Authentic

3. An object is placed at a constant position beyond the focal point with the curvature radius being altered from 0.3 m to 0.9 m at intervals of 0.3 m using the simulation environment. Based on your observations and experiences with the simulation:

- i. Record your observations about the position and size of object and image formed at each value of the curvature radius.

Curvature radius (m)	Object	Image
0.3		
0.6		
0.9		
1.2		

- ii. What conclusion can you draw from your observations in question 3i to explain how the variations in the curvature radius influences the relationship between object and image formed?

.....

Constructive

**Excerpt 4.6:** Illustration of the five dimensions as projected in activity 2 of exemplary intervention 2.

In a Nutshell, the activity sheet element was intended to provide an interactive avenue for learners to make a connection between their prior knowledge, the interactive elements of

the PhET simulation interface and the physics concepts of interest to facilitate meaningful learning of high school physics in order to encourage and motivate learners to be actively engaged throughout the teaching and learning process with ICT (simulations).

#### **4.2.1.5. Collaborative learning approach feature**

This formed the basis for all classroom arrangements envisaged for promoting divergent knowledge expression with the exemplary interventions. All activities designed on the activity sheet as part of the exemplary interventions were geared towards encouraging team work among students in learning the subject matter using the PhET simulations, and providing a platform for discussions as students explore the simulation environment to discover its potentials. Also, by adopting the collaborative approach to learning the subject matter, the *Cooperative* dimension as in the five dimensions for meaningful learning with ICT was put into action to encourage learners to share ideas about the physics concepts among themselves as well as enforce team work capabilities in them.

By all the features discussed herein, the study revealed the exemplary interventions designed by the researcher to be the ICT intervention that fit the realities of the Ghanaian SHS classroom in a manner that makes the teaching of physics interactive.

#### 4.2.2. Research question two (RQ2)

How effective is the ICT intervention in improving teaching and enhancing students learning of concepts in Physics?

In answering RQ2, “effectiveness” of the ICT (PhET simulations)-based intervention was conceptualised to mean the extent to which the five dimensions for meaningful learning with ICT (Howland et al., 2012)—*Active, Constructive, Authentic, Intentional, Cooperative* were realised in the design and implementation of the PhET simulations-based intervention. As has been operationalised in the study (see chapter 2) the five dimensions were defined as:

- *Active*: the use of PhET simulation in lesson activities designed to engage learners in learning the subject matter:
- *Constructive*: the use of PhET simulation in lesson activities designed to stimulate students to reflect upon the subject matter and express their ideas and meaning beyond what is presented them.
- *Authentic*: the use of PhET simulation in lesson activities to connect to students’ personal experiences to real-world.
- *Intentional*: the use of PhET simulation in lesson activities to engage students in diagnosis, evaluation, and improvement of the learning gap.
- *Cooperative*: the use of PhET simulation in lesson activities to engage students in group work for divergent knowledge expressions.

The effectiveness of the ICT intervention in improving teaching and enhancing students’ learning of concepts in physics was measured at two levels: the pre-service teachers’ reported lesson interactiveness (as were evident in the focus group discussions, activity sheets, lesson plan documents, observation data and the five-dimension survey responses) and the Student peers’ perceptions about the interactiveness of the PhET simulations-based lessons (measured by use of focus group discussions with Student peers and Student peers survey data).

#### 4.2.2.1. Pre-service teachers' reported lesson interactivensess

In this study, the pre-service teachers worked in teams of two (DTA1 and DTB1; DTA2 and DTB2), developed their own designed PhET-simulations-supported physics lessons based on their experiences with the exemplary materials developed by the researcher as well as the knowledge they acquired through the initial training workshop of the PDA, and implemented their interventions in two phases (Phase 1 and Phase 2). In Phase 1, the pre-service teachers (DTA1 and DTB1) taught their lessons in two rounds of microteaching among themselves. Similarly, in Phase 2, the pre-service teachers (DTA2 and DTB2) taught their lessons two times first among themselves and second, among their peers (i.e., the pre-service teachers who posed as learners in the study). Thus, in all, four PhET-simulations-supported physics lessons were designed and implemented by the pre-service teachers in the study. Table 4.1 gives an overview of the four PhET-simulations-supported physics lessons.

Table 4.1: Summary of the four PSSPLs.

Intervention	Design Team Designation (DTD)			
	1 <sup>st</sup> Phase		2 <sup>nd</sup> Phase	
	DTA1	DTB1	DTA2	DTB2
ICT-based intervention designated name	PSSPL_1	PSSPL_2	PSSPL_3	PSSPL_4
Topic taught	Reflection and refraction of light	Structure of the atom	Deformation of solids	Frictional force
NLO	2	5	2	2
LD (as stipulated in lesson plan document)	80 minutes	80minutes	80 minutes	80 minutes
school level	SHS1	SHS1	SHS3	SHS2
Name of PhET used (ICT)	Bending Light	Build an Atom	Hooke's Law	Force and Motion: Basics (Friction)
Form of inquiry	Exploratory	Exploratory	Demonstrative	Exploratory
NoA	3	4	5	5

Number of lesson objectives = NLO, Lesson duration=LD and Number of activities= NoA

Evidence gathered from both qualitative and quantitative data in the development and implementation of the intervention by the pre-service teachers helped in examining the

effectiveness of ICT-based intervention. The evidence showed that the PhET simulation-based physics lessons were interactive (effective) in improving their teaching practices and enhancing students' learning of concepts in physics. From the qualitative evidence, it was revealed that the pre-service teachers were able to use the PhET simulation to engage their learners in learning the subject matter (i.e., ACTIVE). Table 4.2 shows evidence (from the focus group discussions) of the extent to which the pre-service teachers perceived the *Active* dimension to have been realised in the design and implementation of each of the four PhET simulations-supported physics lessons.

*Table 4.2: Pre-service teachers' perceptions about the four PSSPLs in relation to the Active dimension.*

Focus Group Interviews (FGI)	Respondent	Active dimension
FGI for PSSPL_1	DTA11 DTB12 DTB11	<ul style="list-style-type: none"> <li>We manipulated the simulations ourselves and recorded our own values so it was interactive.</li> <li>In the course of the lesson, we were involved a lot, and we did almost everything ... So, I realised it was very interactive.</li> <li>We saw that we were all actively participating in the lesson.</li> </ul>
FGI for PSSPL_2	DTA12 DTB11	<ul style="list-style-type: none"> <li>It was very interactive in the sense that we were active throughout the lesson— interacting with the simulation.</li> <li>It was interactive in the sense that for some of the activities, we were using simulations so, we were active.</li> </ul>
FGI for PSSPL_3	DTB22	<ul style="list-style-type: none"> <li>It was active because we gave them the opportunity to explore ...</li> </ul>
FGI for PSSPL_4	DTA21	<ul style="list-style-type: none"> <li>We had the opportunity to interact with the simulations.</li> </ul>

Evidence as shown in Table 4.2 were gathered from different focus group discussions (also referred to as focus group interviews and denoted as FGI) that were conducted after

each first microteaching try-out for intervention PSSPL\_1, PSSPL\_2, PSSPL\_3, and PSSPL\_4. For each intervention, the evidence gathered were in response to the question: “To what extent did the intervention promote interactivity during the lesson?”


Results from Table 4.2 show that the *Active* dimension was realised mainly by engaging learners to interact with the simulation environment themselves or exploring the manipulative features of the PhET simulation environment. This was intended to help them learn the subject matter. Activities that were designed on the activity sheets by the Design Teams also confirmed this. For example, in the activity sheet for PSSPL\_4, the learners were engaged 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.) in order to learn about the subject matter— “Effects of frictional force” (see highlighted areas in Excerpt 4.7).

**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.



Active

**Excerpt 4.7: Projection of the *Active* dimension in Activity 2 of the intervention, PSSPL\_4.**

Similar observations can be made from Excerpt 4.8 where, by use of one of the interactive features of *Bending Light* PhET simulation (i.e., the protractor feature), the pre-service teachers (DTA11 and DTA12) designed activities (Activity 2 of PSSPL\_1) to involve tasks (see highlighted areas in Excerpt 4.8) that were purposed to engage learners to learn about the subject matter on “refractive index of water”.

## ACTIVITY 2

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

Active

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

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

- With the help of the protractor, set the angle of incidence ( $i^\circ$ ) to  $10^\circ$  measure and record the corresponding angle of refraction.
- Repeat the above step with  $i^\circ = 20, 30, 40$  and  $50$  and measure the corresponding angles of refraction for each value
- Compute and record the sine of the angles of incidence and refraction in the activity 2 sheet.

Active

### Excerpt 4.8: Projection of the *Active* dimension in Activity 2 of the intervention, PSSPL\_1.

It was also evident from the qualitative data that the pre-service teachers 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 is presented them (i.e., CONSTRUCTIVE). From the focus group discussions (i.e., FGI) conducted after the implementation of each of the four PhET simulations-supported physics lessons, the pre-service teachers echoed that the lessons were interactive by projecting the *Constructive* dimension. Table 4.3 shows some of the evidence gathered from the focus group discussion data. Specifically, evidence as shown in Table 4.3 were gathered in response to the question: “To what extent did the intervention promote interactivity during the lesson?”. This question was asked at each focus group discussion session with the pre-service teachers after the implementation of intervention PSSPL\_1, PSSPL\_2, and PSSPL\_3. The evidence gathered with respect to PSSPL\_4 were also in response to the same question though, it was asked in different words: “What makes the lesson you just witnessed interactive?”

Table 4.3: Pre-service teachers' perceptions about the four PSSPLs in relation to the Constructive dimension.

Focus Interviews (FGI)	Group	Respondent	Constructive dimension
FGI for PSSPL_1		DTA11	<ul style="list-style-type: none"> <li>We <u>built our own knowledge in doing the activities</u></li> </ul>
FGI for PSSPL_2		DTA12	<ul style="list-style-type: none"> <li>We were able <u>to build our own atom of a particular element for ourselves</u> <u>using the simulation</u></li> </ul>
FGI for PSSPL_3		DTA22  DTA21	<ul style="list-style-type: none"> <li>With the simulation, we helped them [learners] <u>to come up with the learning themselves</u>, making the lesson all student-centred not teacher centred, so it was interactive.</li> <li>Yes, it was interactive because in my last presentation [lesson], <u>there was a particular question on introductory activity</u> which I was not expecting them to write that the applied force equal to minus <math>kx</math> [referring to the mathematical expression for Hooke's law] but one of them knew when he was <u>observing the simulation</u> that there should be a negative sign, <u>so the students learned the concept beyond what I was expecting.</u></li> </ul>
FGI for PSSPL_4		DTA21  DTB22  DTA22	<ul style="list-style-type: none"> <li>Based on the lesson, <u>I understood the concept</u> especially when we say something is opposing motion.</li> <li><u>Once they were exploring</u>, they were able to come up with all the thing that they needed in doing the activities and it helped them to learn by themselves.</li> <li>I think that <u>by using the simulation by ourselves in the activities</u>, we got in-depth understanding of the concept.</li> </ul>

It appears, as can be inferred from the sample comments made by the pre-service teachers in Table 4.3 that the respondents saw the lessons to be interactive because they were able to form their own personal meaning of the subject matter (emphasised by

highlighted areas in Table 4.3). The comments also seem to hint that it was their engagement with the simulation environment in learning the concepts under study (indicated by the underlined statements in Table 4.3) that provoked them to express their ideas and make meaning beyond what had been presented to them. These results were evident during the microteaching session for each intervention. A remarkable evidence of the *Constructive* dimension was witnessed during the first microteaching try-out of the PSSPL\_1 intervention by DTA1 using the *Bending Light* (BL) PhET simulation. This had to do with the latter part of the lesson where the teacher (DTA11) involved his learners in a whole class discussion on a real-life application problem given under Activity 2 of the PSSPL\_1 activity sheet (see Excerpt 4.9) after they 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  $60^\circ$ . Find the angle of refraction.

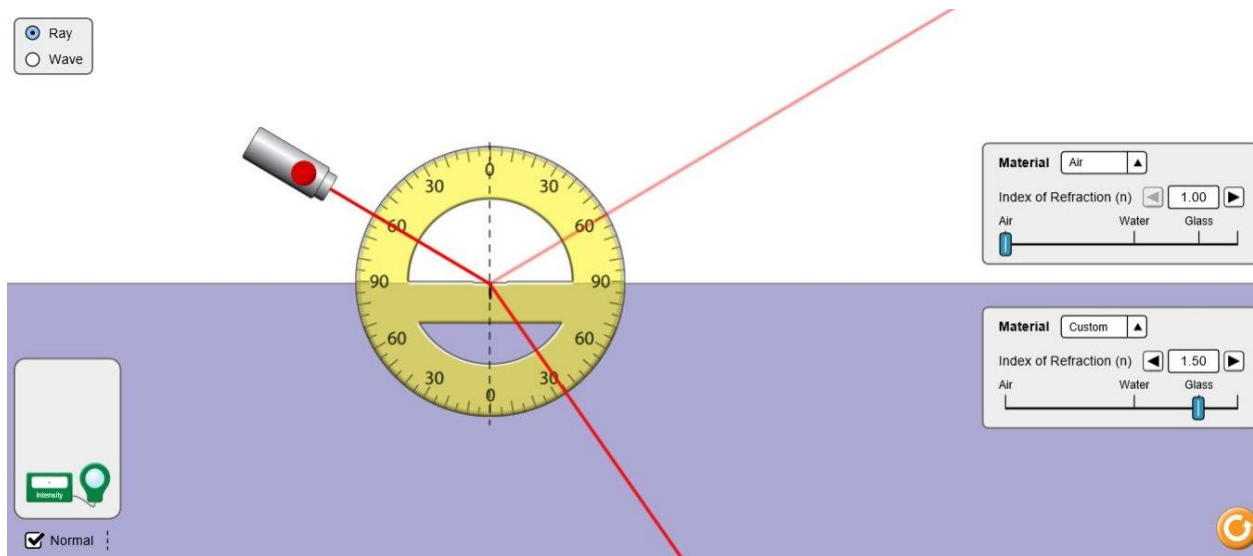
**Excerpt 4.9: Real-life application question under Activity 2 of PSSPL\_1 activity sheet designed by the pre-service teachers in DTA1.**

Led by the teacher, the learner group was asked to share their respective solutions with their colleague students. In particular, the teacher asked the group leader to write his group's solution on the board and to explain how they came by 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 demonstrated using the simulation environment to show how they had arrived at the final answer. Their responses as observed, indicated that they did the following to arrive at the final answer; they:

- clicked on the refresh button in the BL simulation environment—by this action, the simulation interface changed to the fundamental state (see APPENDIX E (E1)).
- adjusted the slider on the material tab for medium of refraction from “Water” to “Glass”. This action, he explained to have been informed by a hint given by the teacher in the real-life application question— “... using the refractive index of glass from the simulation environment”. 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) till its center fell exactly along the “Normal” line in the simulation environment.
- adjusted the light source handle down till the ray of light was at angle 60 degrees away from the “Normal” line with the help of the protractor.
- then finally, measured the corresponding angle that the refracted ray made with the “Normal” line in the glass medium.

With these steps, the result obtained by use of the BL simulation environment with respect to the question under the real-life application section of Activity 2 was as shown in Figure 4.4. Figure 4.4 suggests that at an incident angle of 60 degrees, the angle of refraction is approximately 35 degrees. After these remarkable demonstrations and explanation given by the learner group by use of the BL of the simulation, the teacher, DTA11 seemed astonished at the group’s approach to solving the application question. As I observed, the teacher (DTA11) stood for over 30 seconds before making an utterance. He later hinted that he was perplexed because during the design of the intervention, he and his colleague pre-service teacher (DTA12) had never considered using the simulation environment to solve the real-life application problem. In DTA11’s words this was what he said:

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 just using or simply using the simulation. But then, I was surprised when a group of students, just simply used the simulation, measured and they had the answer straight away. I was very surprised, it was unexpected...; it was a very good attempt on their part.



**Figure 4.4: Snapshot of the alternative solution presented by learners in relation to the real-life application question under Activity 2 of the PSSPL\_1 activity sheet.**

Apparently, the two pre-service teachers (in DTA1) incorporated the real-life application question thinking about a mathematical approach to solving the problem. This was evident in the solution they provided on a slide (as shown in Excerpt 4.10) in relation to the real-life application question under Activity 2 in the course of the lesson. From Excerpt 4.10, the pre-service teacher, DTA11 (in conjunction with his design team member DTA12) solved the problem by employing the mathematical expression for Snell's law of refraction and then, substituted the parameters given in the question as well as that provided by the simulation environment [that is, the angle of incidence= $60^\circ$  (denoted  $i$  in Excerpt 4.10) and refractive index for glass= $1.5$  (denoted  $n_g$ ) respectively] into the mathematical expression as shown in Excerpt 4.10 to arrive at the answer;  $r = 35.26^\circ$  where  $r$  denotes the angle of refraction.

\* **Solution to real life application question**

$$n_g = \frac{\sin i^\circ}{\sin r^\circ}$$

( $n_g = 1.5$  , Angle of reflection = angle of incidence = 60 degrees)

$$1.5 = \frac{\sin 60^\circ}{\sin r^\circ}$$

$$r = 35.26$$

11 2/12/2018

**Excerpt 4.10: Slide presented to learners by DTA11 as the solution to the Real-life application problem.**

Results here suggest that the learner group went beyond reflecting on the subject matter to express their ideas and meaning of Snell’s law beyond what 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 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 pre-service teachers in their design of the activities to engage their learners actively, created an avenue for knowledge construction. This supported the finding from the focus group interview data (i.e., Table 4.3) that suggested that the *Active* dimension was essential in realising the *Constructive* dimension.

Results from the qualitative data (see Table 4.4) also showed that the PhET simulations-based physics lessons designed in this study were purposed to connect to students’ personal experiences to the real-world (i.e., AUTHENTIC).

*Table 4.4: Pre-service teachers' perceptions about the effectiveness of the four PSSPLs in relation to the Authentic dimension.*

Focus Group Interviews (FGI)	Respondents	Authentic Dimension
FGI for PSSPL_1	DTB12 DTB11 DTA11 DTA12	<p>It was authentic because it was based on what or how “reflection” really happens in the real world.</p> <p>It is authentic because we are using simulations to mimic reflection and refraction of light.</p> <p>I think using simulations-supported lessons to teach is the best form of teaching so far for the training I have undergone because, it moves the students from the abstract world to the real-world where the student gets to see what has been said about the concept practically and then it makes learning more meaningful</p> <p>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.</p>
FGI for PSSPL_2	DTA11	It was authentic because we were able solved real-world issues where we built our own element using the protons and other subatomic particles in the simulation.
FGI for PSSPL_3	DTB22	It took us from the abstract way of learning the concept to a real-life experience kind of thing.
FGI for PSSPL_4	DTA21 DTB21	<p>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.</p> <p>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.</p>

This is an indication that the ICT intervention was effective in improving and enhancing students' learning of the physics concepts. The focus group discussion data as indicated in Table 4.4 supported this finding. The evidence provided in Table 4.4 emanated from four different focus group interviews (i.e., FGI) that were conducted based on the first microteaching try-out sessions with ICT-based interventions PSSPL\_1, PSSPL\_2, PSSPL\_3 and PSSPL\_4 respectively. The main question of interest during each of the focus group discussions 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 simulations' use in the lesson effective?". The responses given in this regard by the pre-service teachers as stated in Table 4.4 were all selected based on their projection of the *Authentic* dimension of interactivity. Results in Table 4.4 suggest that the pre-service teachers perceived the PhET simulation-based physics lessons to be interactive because the PhET simulations used provided a platform for them to link their personal experiences in learning the subject matter to the real-world which enabled a shift from learning physics concepts in abstraction to verifying physics concepts practically—they got to see concepts being represented virtually which apparently, made them to appreciate how the physics concepts are applied in the real-world.

The activities designed as part of the lesson artefacts for the PSSPLs confirmed the pre-service teachers' comments in Table 4.4. For example, one of the activities (i.e., Activity 2 see Excerpt 4.11) designed by DTB1 was found to contain the element of authenticity in the sense that it was designed to help learners to have a real-life experience in using the number of protons to verify the characteristics (i.e., mass number and net charge) of various elements on the periodic table in order to appreciate how each of these characteristics were influenced by subatomic particles such as protons, electrons or neutrons. Thus, under Activity 2 (see Excerpt 4.11) of the PSSPL\_2 intervention, the *Build an Atom* (BA) (Figure 4.5) PhET simulation environment was employed to realise the *Authentic* dimension in a way that helped learners to determine the:

- mass numbers of some specified element (i.e., Helium, Beryllium, Carbon, Nitrogen, and Neon) given their neutron numbers. For specified values of the neutron number,

learners were tasked to drop protons in the nucleus area of the simulation until the feedbacks from the simulation corresponded to the element indicated on the activity sheet; this was intended to help the learners see for themselves the number of protons that constitute a particular element in its nucleus for each number of protons specified.

- corresponding net charges of each element as protons are added to the neutrons in the nucleus as responded and represented by the BA simulation. It was expected that learners record the net charge values from the “Net Charge” dropdown menu in the simulation environment. However, the focus of this task was to help the learners link their experiences to understanding which of the specified subatomic particles (i.e., protons and neutrons) in reality, inform the “net charge” of an element.
- effect of protons and electrons on the net charge of specified elements. This required learners to observe and see for themselves the changes in the net charge values as shown in the simulation as more electrons are added to the atomic structure of specified elements.

Protons:  
Neutrons:  
Electrons:

**Nucleus:** this is where protons and neutrons are to be dropped.

**Electron orbit:** this is where the electrons are to be dropped.

**Model:**  
 Orbits  
 Cloud

Protons

Neutrons

Electrons

Element

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Uut	Fu	Lv	Uus	Uuq	

Net Charge +

Mass Number +

**Show**

Element

Neutral/ion

Stable/unstable

Figure 4.5: Build an Atom PhET simulation environment.

## ACTIVITY 2

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

In the simulation environment;

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

Use the number of protons to verify the elements.

AUTHENTIC

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

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

.....  
.....

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

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

.....  
.....

AUTHENTIC

**Excerpt 4.11: Projection of the *Authentic* dimension in Activity 2 of the intervention, PSSPL\_2.**

Evidence presented with respect to Activity 2 as designed by DTB1 shows that the *Authentic* dimension was also realised by provoking ownership on the part of the learners through authentic tasks. This was key to making the lesson interactive (effective). The

activities designed by DTA1 on the topic: *Reflection and refraction of light* (i.e., PSSPL\_1) also corroborated this finding about the *Authentic* dimension. For example, tasks such as that shown in Excerpt 4.12a were designed to subject learners to verifying the first law of reflection by themselves using the BL simulation environment (see Excerpt 4.12b) as a way of helping them to acquire some sense of ownership in understanding what the laws of reflections stipulate in an authentic atmosphere.

## ACTIVITY 1

### Verification of the laws of reflection

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

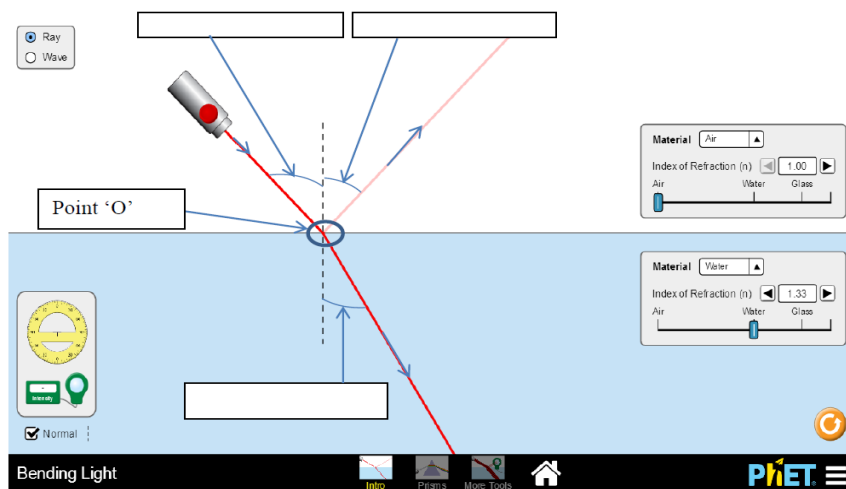
- Using your previous knowledge, using the simulation environment, identify the incident ray, the reflected ray and the normal
- With the help of the protractor, set the angle of incidence ( $i^\circ$ ) to  $10^\circ$
- Measure and record the corresponding angle of reflection in the table below
- Repeat the above step with  $i^\circ = 20, 30, 40$  and  $50$  and measure and record the corresponding angle of reflection for each value of  $i^\circ$

Incident angle	$10^\circ$	$20^\circ$	$30^\circ$	$40^\circ$	$50^\circ$
Reflected angle					

Authentic tasks

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

**Excerpt 4.12a: Projection of the *Authentic* dimension in Activity 1 of the intervention, PSSPL\_1.**



**Excerpt 4.12b: Bending Light PhET simulation as pasted under Activity 1 of the intervention, PSSPL\_1.**

“Question 1.” as indicated in Excerpt 4.12a seems to be the triggering element for provoking ownership on the part of learners through the “authentic tasks” (as indicated in Excerpt 4.12a). Specifically, the question required learners to use the “point ‘O’” in the snapshot from the simulation (Excerpt 4.12b) as a point of reference, an object of attention, as well as a link to stimulating their minds to what actually happens at the point of incidence as a ray of light is incident on a reflective surface in relation to the *First law of reflection*.

In addition, the qualitative data showed that the pre-service teachers used the PhETs in the design of their respective lesson activities to engage learners in diagnosis, evaluation, and improvement of the learning gap (i.e., INTENTIONAL). Each of these elements of the *Intentional* dimension was realised depending on how the pre-service teachers in each Design Team chose to align the affordances of the simulations 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 showed evidence of this using the *Force and Motion: Basics (friction)* PhET simulation environment. As illustrated in Figure 4.6, 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 employed by DTB2 to align with the various tasks enlisted under Activity 1 in order to achieve the learning goal set for Activity 1: “Define frictional force” (labelled as 1 in Figure 4.6). In particular, the red and orange arrows (i.e., label A) in the simulation environment represents 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 below 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 4.6) that the learners were engaged more in the diagnosis aspect of the *Intentional* dimension with the *Force and Motion: Basics (friction)* PhET simulation in achieving their learning goal of defining frictional force.

Similar evidence sufficed for the other lessons designed in ways that projected the *Intentional* dimension in ascertaining the effectiveness of the ICT (simulation) interventions designed in this study.

Specific objectives	By the end of the lesson, the student should be able to: <ul style="list-style-type: none"> <li>➤ define frictional force <span style="border: 1px solid black; padding: 2px;">1</span></li> </ul>
---------------------	--

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

A & B  
A  
A, B, & C  
D & B  
1

1

**Diagnosis**

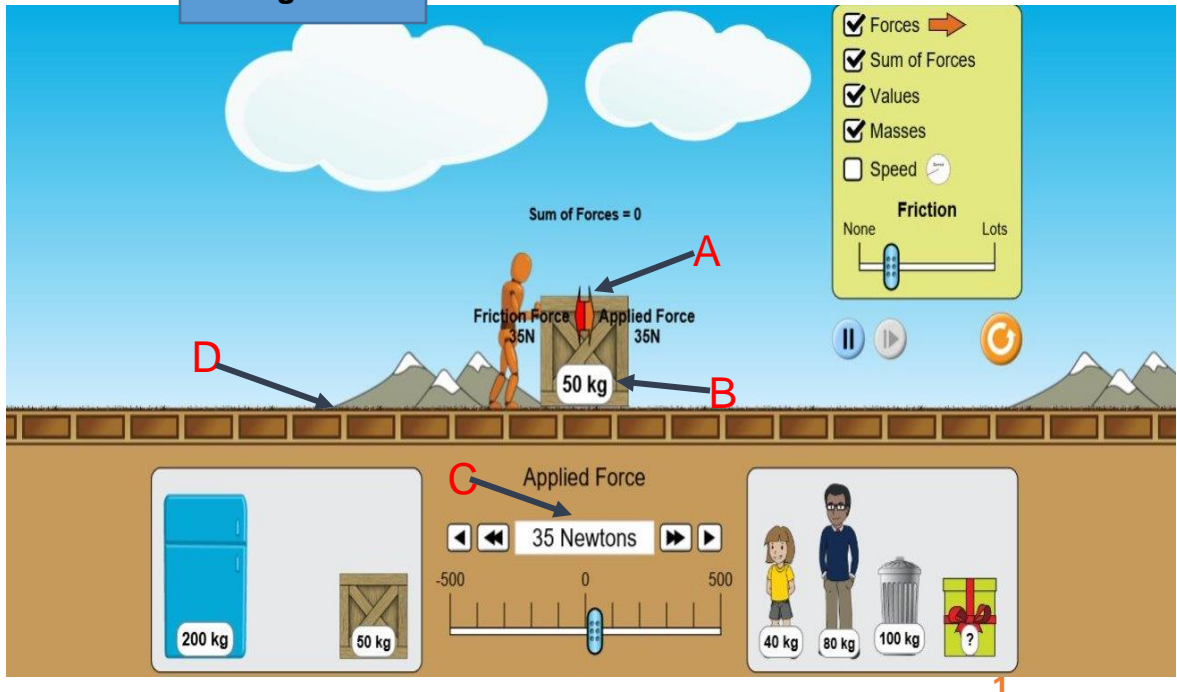


Figure 4.6: Projection of the *Intentional* dimension in Activity 2 of the intervention, PSSPL\_4.

With the *Cooperative* dimension, the qualitative evidence gathered in this study after the design and implementation of all four PhET simulations-supported physics lessons showed that the pre-service teachers used their respective PhET simulation environment to engage students in group work for divergent knowledge expressions where they shared ideas in forming their own meaning of various physics concepts that were taught. Some of the evidence in this regard, resulted from different focus group interviews conducted with the first and second cohorts of pre-service teachers—specifically, after their first microteaching try-outs with their respective simulations-based interventions. For example, from the focus group interview conducted after DTA11 had taught the lesson on the topic: *Reflection and Refraction of light* (using the PSSPL\_1) among his colleagues (in the first cohort), DTA11 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, DTA11 perceived his lesson with the PSSPL\_1 intervention as interactive because he, in his capacity as the teacher instructed the learners to work in groups during the instructional process.

In response to the same question, DTA12 and DTB11 who posed as learners during DTA11’s teaching with the PSSPL\_1 intervention supported DTA11’s view by adding that:

DTA12: We interacted with our colleagues during the lesson.

DTB12: We shared ideas with our colleagues during our work so, there was this cooperative element.

In an attempt to answer the question: “Which element made the ICT-based lesson interactive?”, similar comments that projected the *Cooperative* dimension of interactivity were gathered from the second cohort of pre-service teachers during focus group interview sessions that were conducted after the first microteaching try-out with interventions PSSPL\_3 and PSSPL\_4. For instance, one of the pre-service teachers

(with designation DTA22) who posed as a learner during the first microteaching session with the PSSPL\_3 intervention expressed his view about the lesson on the topic: *Deformation of solids* as facilitated by DTA21 as indicated below:

DTA22: Cooperative because we worked in groups.

DTB21, who was a learner during the lesson enacted by DTA21 added in support of DTA22's comment that:

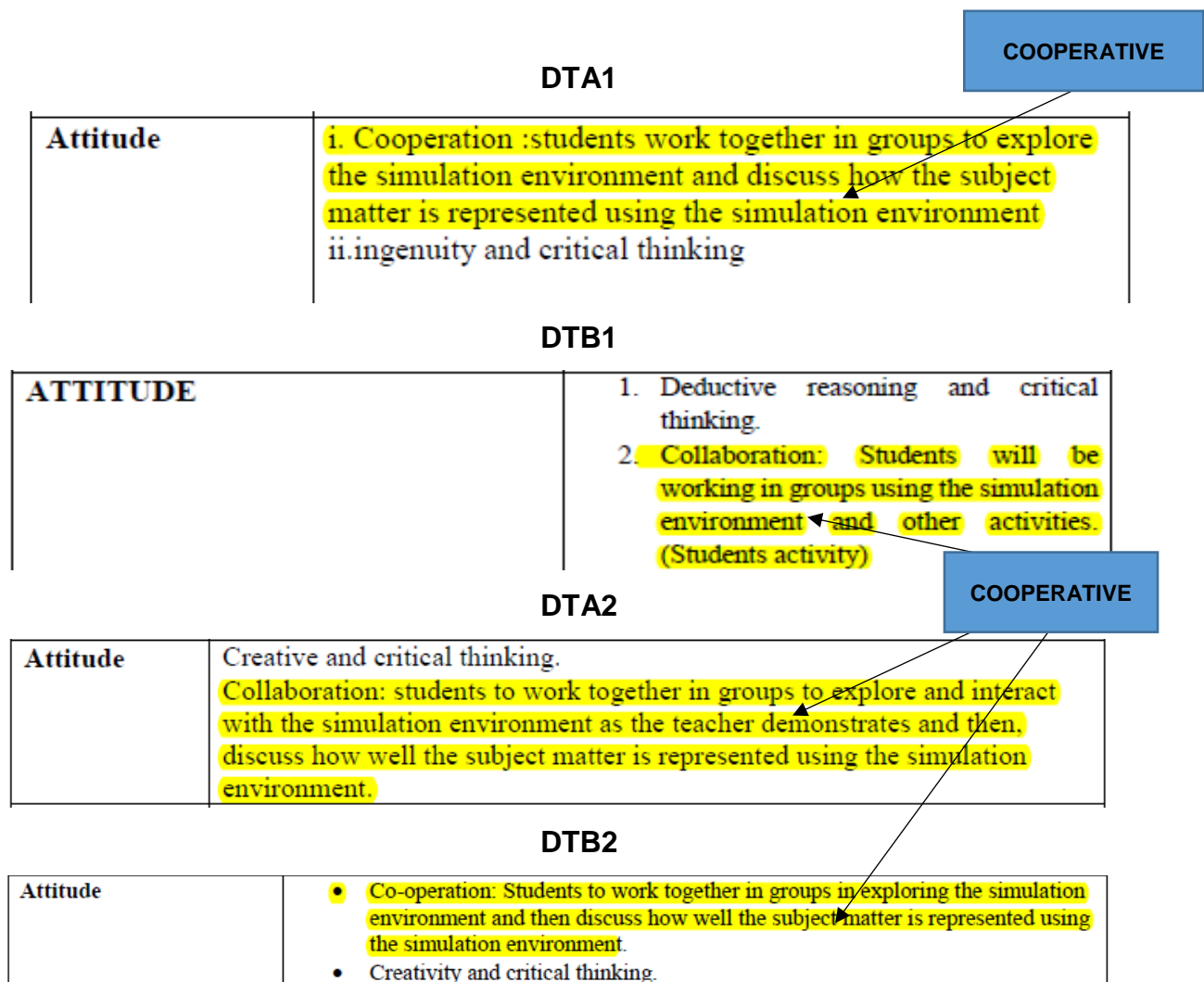
... we were made to discuss our answer.

DTB21 who was the facilitator during the first microteaching try-out with the PSSPL\_4) seemed quite confident that his lesson was interactive because the learners collaborated to work together during the lesson. He had the following to say:

The learners in my lesson interacted with their co-learners by working in groups and they also shared ideas among themselves.

The lesson plan documents designed and developed by all the Design Teams as part of the lesson artefacts for their respective interventions threw more light on the findings from the focus group discussion data. In particular, aspects of the lesson plan document suggested that the *Cooperative* dimension was not only incorporated for facilitating divergent knowledge expressions (as the focus group data suggests), but was also situated throughout the lesson activities designed for the PhET simulations-supported interventions as the sustaining element for the realisation of each of the four other dimensions (i.e., *Active*, *Constructive*, *Authentic*, and *Intentional*). This suggests that in all the lesson activities designed with the PhETs whether purposed for realising *Active*, *Constructive*, *Intentional* or *Authentic* dimension, the collaborative approach to learning (i.e., the *Cooperative* dimension) was a pre-requisite for achieving the learning goals set for each activity in an effective manner. An example of this finding is shown in Figure 4.7 as observed from the lesson plan documents designed by each Design Team. Figure 4.7 suggests that per the stipulated "attitudes" required of the learners for effective learning

of the subject matter using the PhETs, the pre-service teachers envisioned the group work element as a necessary condition (though not sufficient) for bringing about interactive teaching and learning with the interventions throughout the instructional process. Thus, it appears that the *Cooperative* dimension's position as the sustaining element in the design of the PhET-based lesson activities served as the basis for motivating the learners to do the lesson activities. This facilitated enhanced student's learning of the various physics concepts discussed with the interventions as well as helped the learners to uncover the potentials of each interactive feature in the PhET simulation environments used in the design of the lesson activities all by themselves.



**Figure 4.7: Projection of the *Cooperative* dimension in lesson plan documents of all four the interventions.**

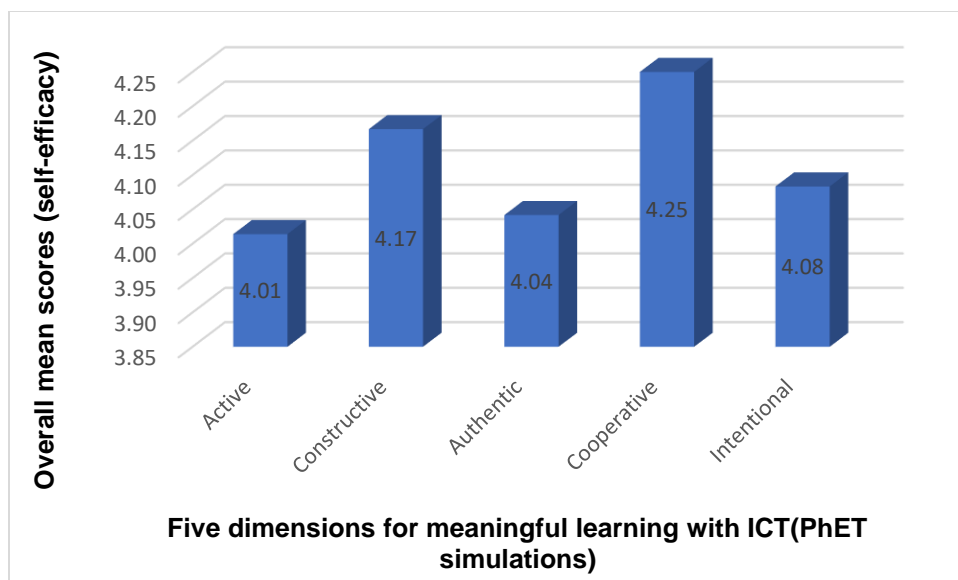
The overall picture as reported by the pre-service teachers from the afore presented results about the ICT (simulations)-based lessons designed in this study suggests that the pre-service teachers believed the lessons (PSSPLs) were interactive (i.e., projected all the five dimensions for meaningful learning with ICT by Howland et al. (2012)). This seems to suggest that the teaching approach adopted by the pre-service teachers for teaching the physics concepts selected for the design of the intervention was learner-centred.

The effectiveness of the ICT intervention was also determined quantitatively from the analyses of the five-dimension survey (see Table 4.5). Analyses in this regard corroborated the qualitative evidence. The survey consisted of twenty-nine items that were grouped under the *Active* (6 items), *Constructive* (6 items), *Authentic* (6 items), *Intentional* (4 items) and *Cooperative* (7 items) dimensions. Possible answers to items on the five-dimension questionnaire were on a scale—ranging from strongly disagree (1) to strongly agree (5). An average of 3 and above indicated a positive favourable opinion while below 3 indicated a negative opinion of the pre-service teachers' responses. Table 4.5 highlights the results of the five-dimension survey as expressed by participants in assessing the extent to which each of the five dimensions for meaningful learning with ICT was realised during the first microteaching try-out sessions of both Phase 1 and Phase 2 of the study. The results indicate that there were favourable responses for all the five dimensions for meaningful learning in all the four lessons confirming earlier results (from qualitative data) that pre-service teachers believed their lessons were interactive. The results seem to suggest that pre-service teachers rated high scores for all the dimensions with respect to the lessons on *Atomic Structure* and *Frictional Force* as compared to the other three lessons (see Table 4.5). The lesson on *Deformation of Solids* recorded the least scores for all the dimensions, but does not seem to indicate that it was not interactive in nature. The least score could be attributed to the approach (i.e., demonstrative form of guided inquiry) adopted by DTA2 for the delivery of the lesson using the *Hooke's law* PhET simulation environment.

Table 4.5: Results of the five-dimension survey as expressed by participants for both phase 1 and phase 2 on each of the four PhET simulations-based physics lessons designed and enacted in the study

Subscale	Reflect. & Refract. of Light (DTA1)		Atomic Structure. (DTB1)		Deformation of Solids (DTA2)		Frictional Force (DTB2)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Active	4.11	0.481	4.33	0.333	3.33	0.764	4.28	0.096
Constructive	4.33	0.333	4.67	0.000	3.17	0.928	4.50	0.167
Authentic	4.28	0.096	4.56	0.255	3.00	0.833	4.33	0.441
Intentional	4.33	0.360	4.52	0.297	3.38	0.787	4.76	0.218
Cooperative	4.17	0.382	4.42	0.804	3.33	0.577	4.42	0.289

The overall picture as depicted by Figure 4.8 points to the fact that the *Cooperative* dimension in which the pre-service teachers used the PhET simulation to engage students in group work for divergent knowledge expressions was the most projected in their lessons. A possible reason for this could 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*. The third had to do with the *Intentional* dimension while the least was reported in the *Active* dimension. Figure 4.8 provides an overview of the overall ratings of the dimensions of meaningful learning as perceived by the pre-service teachers.



**Figure 4.8: Overall results for the five-dimension survey as expressed by participants for both Phase 1 and Phase 2 on all four PhET simulations-based physics lessons designed and enacted in the study.**

#### **4.2.2.2. Student peers' perceptions about the interactiveness of the PhET simulations-supported physics lessons**

In this study, Student peers' perceptions about the interactiveness of the PhET simulations-based lessons were also examined as part of the evaluation of the effectiveness of the ICT intervention in improving teaching and enhancing students' learning of concepts in physics. Nine (9) Student peers served as learners in Phase 2 of the study during the second microteaching try-outs of the PSSPLs designed by DTA2 (*Deformation of Solids, DOS*) and DTB2 (*Frictional Force, FF*) and reported their perceptions about the extent of interactivity of the lessons in a focus group discussion and also, in the responses they gave to student peer questionnaire.

The Student peers reiterated in their focus group discussions that they found the lessons interactive when asked the question: "Was the lesson interactive?". Interestingly, when asked to explain further, their responses showed elements of the *Active, Constructive,*

*Authentic, Intentional, and Cooperative* dimensions even though they had no prior knowledge about these dimensions. For example, from the focus group discussion after the enactment of the lesson on *Deformation of Solids*, the following statements were made by the Student peers in response to the question “Was the lesson interactive?”:

Student peer 4: Yes, because we worked in groups throughout the lesson [COOPERATIVE]...

Student peer 5: Because we were working in groups [COOPERATIVE] and we were able to come out with the correct formulae for the activity [CONSTRUCTIVE].

By this statement, Student peer 5 was referring to Activity 2 of the intervention PSSPL\_3 activity sheet as shown in Excerpt 4.13 with emphasis on how the *Cooperative* element “discuss in group” as stipulated in the activity sheet helped him and his co-learners to construct their own knowledge mathematically about how the applied force influences displacement (as expected in question 1 of Activity 2; see Excerpt 4.13).

**Activity 2:** How applied force influences displacement.

In this activity, you will be verifying Hooke's Law.

Per your observation of the demonstration exercises using the simulation, discuss in groups to answer the questions below:

COOPERATIVE



1. By observing the demonstration, complete the table below with the required values.

Applied force	Spring constant (K)	Displacement (X)	Spring force (F)
50N			
100N			

Compare the values in the table above and write an equation relating the spring force (F), displacement (X) and the spring constant (K).

.....

CONSTRUCTIVE



**Excerpt 4.13: Aspect of Activity 2 as designed by DTA2 on the lesson, *Deformation of Solids*.**

Student peer 9 also supported Student peer 5's comment in relation to Activity 2 of the activity sheet designed by DTA2 as part of intervention PSSPL\_3. Seemingly, this was also related to question 1 of Activity 2 (see Excerpt 4.13) where the learners were expected to “write an equation relating the spring force (F), displacement (X), and the spring constant (K)” based on their observation of the simulation environment under exploration. In this regard, Student peer 9 had the following to say:

Student peer 9: When we were learning with the simulations, we worked in groups to prove the formulae [COOPERATIVE]...

Student peer 6: In Activity 2, there was one approach that I think was very interactive; we started by finding what the features in the simulation meant [INTENTIONAL] and then, afterwards, we were asked to predict the purpose of each of the features [CONSTRUCTIVE].

Comment by Student peer 6 had to do with the “Introductory Activity 2” of the Introductory activity sheet designed by DTA2 as part of the PSSPL\_3 intervention (see APPENDIX D(D4)). As the comment suggests, the *Intentional* as well as *Constructive* elements as incorporated in the design and implementation of the “Introductory Activity 2” seemed to be the reason why Student peer 6 perceived the lesson on *Deformation of Solids* to be interactive.

Similarly, for the lesson on *Frictional force*, elements of the five dimensions were evident in the results gathered during the focus group discussion from the Student peers about the interactiveness of the lesson. They had the following to say in response to the question: “Was the lesson interactive?”:

Student Peer 1: it is based on my personal interaction [experience] with the simulation [AUTHENTIC].

Student peer 2: Apart from the teacher doing it, we also got the chance to do it in groups [ACTIVE; COOPERATIVE], and to see whether what the teacher did was achievable [AUTHENTIC].

Student peer 3: After each activity, the groups had to present. So, we get to know the ideas of other groups [COOPERATIVE] ...

Student peer 5: This lesson, we did not easily get bored because at that point where we were getting bored, we were interacting with the simulation [ACTIVE]...

Student peer 8: In our groups we were discussing whatever we saw from the simulation as we played with it. ...so, there was some sort of interaction between us [COOPERATIVE].

Responses given seem to confirm the finding that the Student peers perceived the two lessons to be interactive (effective). However, as can be inferred from their responses, it appears that the element of interactivity most projected from their perspective was the *Cooperative* dimension. This confirms the pre-service teachers' perception that the *Cooperative* was the most projected dimension among the five dimensions. The results therefore suggest that the two Design Teams, DTA2 and DTB2 used the PhET simulation in most of the lesson activities they designed to engage students in group work for divergent knowledge expressions in a way that promoted the lessons to be interactive and learner-centred.

The survey data results further confirmed that the Student peers perceived the lessons they observed to be interactive in nature. Table 4.6 shows that the Student peers rated all dimensions of the interactivity of the lessons high. In general, the *Cooperative* dimension (M= 4.67, SD= 0.343) in which they worked in groups to learn various concepts in physics using the PhET simulation was the most projected by the Student peers—confirming results from the qualitative data. This was followed by *Authentic* (M=4.57, SD= 0.358), *Constructive* (M=4.50, SD=0.597) and *Intentional* (M=4.24, SD=0.424) dimensions. The least was reported in *Active* (M=4.22, SD=0.412) as was observed in

the findings with the pre-service teachers. Also, there were not much difference between the dimensions of interactiveness between the two lessons as reported by the Student peers. This seem to suggest that both pre- service teachers who taught the two lessons adopted learner-centred strategies. Table 4.6 gives an overview of the results for Student peers survey data.

*Table 4.6: Student peers’ responses about the interactiveness of the lessons from the Student peers’ survey.*

Subscale	Deformation of Solids DTA2 (N=9)		Frictional Force DTB2 (N=9)		Overall (N=9)	
	Mean	SD	Mean	SD	Mean	SD
Active	4.07	0.465	4.37	0.309	4.22	0.412
Constructive	4.48	0.444	4.52	0.474	4.50	0.597
Authentic	4.56	0.408	4.59	0.323	4.57	0.358
Intentional	4.11	0.440	4.37	0.388	4.24	0.424
Cooperative	4.63	0.351	4.70	0.351	4.67	0.343

#### **4.2.2.3. Reasons for the interactivity achieved with the ICT intervention**

The results presented in addressing RQ2 pinpoints to the finding that the PhET simulation-supported lessons were interactive and learner-centred; hence, effective in improving teaching and enhancing students’ learning of physics concepts. However, it is worth mentioning that there were a number of reasons that could have accounted for the interactivity (effectiveness) achieved with ICT interventions developed in this study.

One of the reasons was found to be because of the teacher’s role as a facilitator during enactment of the simulation-based lessons. This was revealed during the focus group discussion sessions where the participants hinted that the role of the teacher as a facilitator during the lessons’ implementation made their teaching and learning process with the intervention a success. Four of the pre-service teachers had the following to say on this issue:

DTA11: After every activity, we go through step by step and he [the teacher] also gives us summaries after each activity...

DTB12: The lesson was student-centred, ... virtually we did 80% of everything, the teacher only came in to give us a summary of the activities we had done in our group. So, he was a guide...

DTB22: The fact that the lesson was student-centred, the teacher had to do a little and then, come to summarize the solution for us. So, I think that one, he guided us.

DTA21: Most of the activities were student-centred. The teacher only came in to summarize everything that we had done after our group discussions. I liked his style, because we saw that what we obtained after constructing our own knowledge with the simulation was not different from what the teacher presented in his summary.

Evidence as reported here suggest that the facilitating role of the teacher was a crucial element that made the teaching and learning with the simulations-supported physics lessons effective during implementation. The responses from the pre-service teachers also seem to give an indication that the facilitating role of the teacher was realised through the provision of summaries on the concepts explored.

In most of the PSSPLs lesson plan documents, it was evident that the pre-service teachers intended to guide their learners in using the PhET simulation environment they had chosen for the design of their respective ICT interventions during the instructional process. The facilitating roles identified in the various lesson plan documents appeared more learner-focused and came in different forms. These involved:

- 1) providing summaries on the concepts explored with the simulation environment in order to help learners clear their misconceptions and fill in the gaps in their knowledge—this corroborates finding from the focus group discussion.
- 2) engaging learners' prior knowledge about physics concepts that were relevant for understanding the topic selected for the intervention. The lesson plan documents provided supporting evidence in this regard (see Table 4.7).

*Table 4.7: Excerpts from lesson plans by each design team to show the various ways in which the pre-service teachers engaged students' prior knowledge during the introductory aspects of their lessons.*

PSSPL_1 (DTA1)	PSSPL_2 (DTB1)
<p>Teachers introduces the lesson by asking students the following questions:</p> <p>i. define: reflection, refraction</p> <p>ii. state the laws of reflection and refraction</p>	<p>Teacher gives each group of students review question sheet on which they are to:</p> <ul style="list-style-type: none"> <li>• Circle the true statement about an atom</li> <li>• Identify the sub-atomic particles based on the description that best fit the particle.</li> <li>• To draw the structure of an atom.</li> </ul>
PSSPL_3 (DTA2)	PSSPL_4 (DTB2)
<p>Teacher displays a picture that is associated with deformation of springs, and asks students to:</p> <ul style="list-style-type: none"> <li>❖ identify what tool it is.</li> <li>❖ describe what happens to the tool when they try to put battery inside a torch.</li> </ul>	<p>Teacher reviews student's previous knowledge by asking them the following questions.</p> <p>(1)What is force?</p> <p>(2) State 4 types of force.</p>

Evidence in Table 4.7. suggest that the pre-service teachers engaged their students' prior knowledge about different concepts in physics by use of questions, pictures and activity sheets. The outcome of this mode of facilitation as observed during the instructional process for each intervention was that, learners were encouraged to: 1) give responses to questions asked by the teacher either orally or in writing, 2) reflect on their previous physics concepts, and 3) connect their real-life experiences to the subject matter.

- 3) supervising the learners as they worked in groups to do the lesson activities designed on the activity sheet. In particular, the pre-service teachers took keen interest in how the students collaboratively worked in groups to explore the simulation environment and consequently, to answer questions on the activity sheet. The focus here was on identifying the challenges encountered by students in doing the activities and to help the students where needed. This was confirmed

by one of the pre-service teachers (i.e., DTA11) who posed as a learner during the first try-out of the intervention PSSPL\_1 which was enacted by DTB11. The following was the comment made by DTA11:

In the course of the lesson, though we did almost everything, the teacher came around to supervise which was helpful. For example, in my group he explained some points to us since we had challenges in terms of the use of the simulation. So, I realised it was interactive.

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

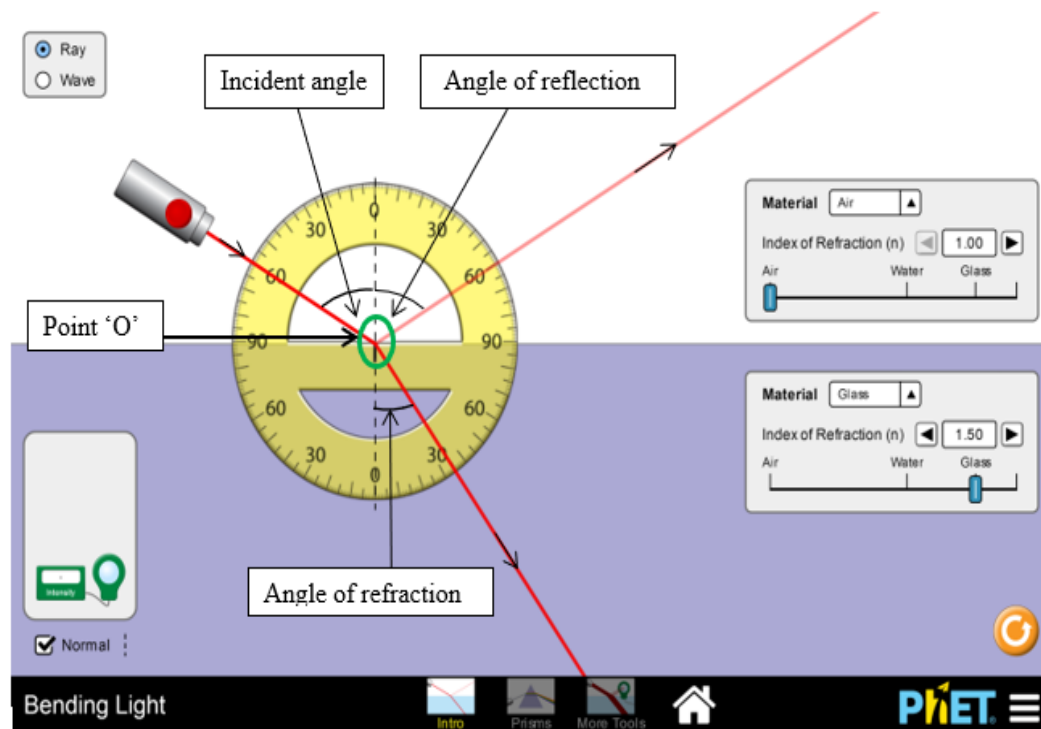
In the course of the activity that he gave us, when we were solving, we realised that under normal circumstances we had the mathematical formulae for solving it, but based on the simulations we called upon him [referring to the teacher] and we asked if he could help us. Then, he told us that we were using water instead of glass; ... but we did not use that so, he asked us to change it; in other words, he helped us to use the simulations appropriately.

DTB12 reiterated DTB11's statement as he explained further as follows:

In the course of the activity [Activity1] that he gave us, when we were verifying Snell's law using the simulation, the answers we were getting were different from the answers we got when we solved it mathematically since we knew the formulae. We did not understand. So, we called upon the teacher for help and then he pointed out to us that we had set the second medium in the simulation to water instead of glass. His supervision helped us...

Comment made by DTA11 and DTA12 had to do with Activity 1 of PSSPL\_1 intervention (first draft). The activity required learner to set the *Bending Light* PhET simulation environment to specific settings as shown in Excerpt 4.14 in order to achieve their learning goals for that activity in relation to the lesson: *Reflection and*

*refraction of light.*



**Excerpt 4.14: Specific settings of the Bending Light PhET simulation environment as explored by DTA1 in their design of lesson Activity 1 for the first draft of PSSPL\_1 intervention.**

As can be inferred from the PhET simulation in Excerpt 4.14, the second medium of propagation of the light ray was “Glass” and not “Water”. This explains why their simulation results differed from that which they had obtained without the simulation. Hence, the facilitating role of the teacher (in supervising the learners’ activities) in this situation was crucial in helping the learners to use the simulations to learn their subject matter effectively.

- 4) creating platforms for group and whole class discussions. With this mode of facilitation, the pre-service teachers led, encouraged and motivated learners to share their ideas and to give explanations on how they used the simulation

environments afforded them to achieve their learning goals for the tasks assigned to them on the activity sheets.

The lesson plan documents designed as part of the lesson artefacts for each of the four ICT (simulation)-based interventions designed in this study also confirmed these results. An example of this is shown in Excerpt 4.15a.

<p><b>Main activities</b> (60 minutes)</p>	<p><b>Activity 1: Verification of the laws of reflection (20minutes)</b></p> <p>In order for students to construct their own knowledge on how to verify the laws of reflection, teacher guides students to do the following in groups</p> <p>Use a snapshot from the simulation environment to help students setup their simulation for activity one in relation to the simulation element such as material, ray and the protractor option</p> <p>With the help of the protractor, set the angle of incidence (<math>i^\circ</math>) to <math>10^\circ</math> measure and record the corresponding angle of reflection.</p> <p>Repeat the above step with <math>i^\circ = 20, 30, 40</math> and <math>50</math> and measure the angle of reflection for each value</p> <p>Identify the similarities and differences between the angles of incidence and reflection recorded</p> <p>Briefly explain the observations based on the similarities and differences in the values recorded above.</p> <p>Teacher then calls a representative from each students group to present their findings for whole class discussion</p> <p>Teacher then summarizes the key physics concepts in activity one, and also presents the solution.</p>	<p>Engagement of students' prior knowledge</p> <p>Based on the snapshot which has been pasted in the activity sheet, students set up the simulation environment as guided by the teacher in order to verify the laws of reflection. And then answer questions on the activity sheet that fall under activity one based on their prior and newly acquired knowledge.</p> <p>Provision of summaries</p> <p>A representative from each group of students presents the solution to the problem for whole class discussion in order to arrive at a consensus.</p> <p>Some expected discussion points from students</p>
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**Excerpt 4.15a: illustration of facilitating role of a teacher as depicted in the lesson plan document for the PSSPL\_1 intervention developed by DTA1.**

The results from the qualitative data therefore pin points that all the four facilitating modes adopted by the pre-service teachers promoted interactivity in the physics classroom with the learner at the centre of the teaching and learning process.

Another reason for the interactivity achieved was the minimal level of guidance provided on the activity sheets (that was developed by the Design Teams) to facilitate students' exploration of the simulation environment during the instructional process. This was

ensured by pre-service teachers (Design Teams) through the use of instructions, snapshots from the simulation environment, content-driving follow-up questions, and tables in the design of the activity sheet. The instructions were designed to be specific and brief in order to give concise guidance to learners on each activity. For example, with the intervention PSSPL\_1, Design Team, DTA1 provided instructions that gave step by step directions for setting up of the simulation environment to desirable interface as well as carrying out the lesson activities. Excerpt 4.15b shows sample instructions given by DTA1 on the activity sheet for Activity 2.

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

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

**Excerpt 4.15b: Sample instructions as given by DTA1 under Activity 2 of the PSSPL\_1 activity sheet.**

The snapshots were mostly pictures of the unexplored interface of the PhET simulation environments. These were intended to serve as the starting point for adjusting the interactive features (i.e., tabs and menus) in the simulation environments in order to help learners arrive at specific settings of the simulation as required for achieving specific content goals. An example of this was evident in the PSSPL\_2 activity sheet as shown in Excerpt 4.15c, where DTB1 used a screenshot from the unexplored *Build an Atom* PhET simulation environment to guide learners in arriving at specific settings.

## ACTIVITY 1 SCREENSHOT

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

The screenshot shows the 'Build an Atom' simulation interface. At the top left, a yellow box contains labels for 'Protons:', 'Neutrons:', and 'Electrons:'. The central area displays a nucleus with an orange 'X' and two concentric blue dashed circles representing electron orbits. Below the nucleus are three bowls: 'Protons' (orange), 'Neutrons' (grey), and 'Electrons' (blue). To the right, three yellow panels show 'Element' (a periodic table with a blank space), 'Net Charge' (a scale from -2 to +2 with 0 selected), and 'Mass Number' (a balance scale with 0 selected). Below these panels is a 'Model' section with radio buttons for 'Orbits' (selected) and 'Cloud'. A 'Show' section has checkboxes for 'Element' (checked), 'Neutral/ion' (checked), and 'Stable/unstable' (unchecked). A circular arrow icon is to the right. The bottom bar includes 'Build an Atom', navigation icons for 'Atoms', 'Symbol', 'Game', and 'Home', and the PhET logo.

SCREENSHOT 'A'

**Excerpt 4.15c: sample snapshot of the BA simulation that was used by DTA2 to guide learners.**

The content-driving questions (such as that depicted by Excerpt 4.15d) were designed to direct the learners to: 1) explore the simulation environment given certain parameters; 2) pay attention to the feedbacks that emanate from the simulation environment upon adjusting the simulation settings or manipulating its interactive features based on parameters to be determined; and 3) to make meaning of their observations of the simulation environment as well as relate them to the set goals assigned to each activity. In addition, the pre-service teachers used content driven follow-up questions as guides for learners to represent their ideas properly on the activity sheets and to form their own understanding about the physics concepts under investigation as informed by their interaction with the PhET simulation environment.

(iii) From the simulation, why did the body of mass 50kg not move when the force X was applied on it.

.....  
.....  
.....

(iv) What is the nature of the surface of the floor in contact with the body of mass 50kg as explored in the simulation

.....

(v) In your own words, define frictional force.

.....

**Excerpt 4.15d: Example of content-driven follow up question as designed by DTB2 under Activity 1 of the PSSPL\_4 Activity sheet on the topic: *Frictional force*.**

Tables were used for the purpose of providing a systemic guide for students to present and organise their ideas in a specific manner. This was confirmed by one of the pre-service teachers during an interview session where he revealed the rationale behind his team’s use of a table by indicating that:

Without the table, they [the students] might have different ways of presenting the data they had collected [from their interaction with the simulation environment]. The aim was to get a uniform way of gathering or collecting data from the simulation.

**4.2.2.4. Factors that inhibited the effectiveness of the ICT-based intervention**

In all, the results presented at all two levels in addressing the RQ2, echo that the ICT intervention developed in this study was effective, interactive, and student-centred. This is an indication that the ICT (simulation)-based intervention facilitated a shift in the pre-service teachers’ way of teaching from a teacher-centred approach to a learner-centred approach. Nevertheless, the success of the ICT intervention in this study was not without limitations. In particular, time was an issue during both the first and second microteaching try-outs of the intervention. In my observation of the pre-service teachers during the

delivery of the simulations-based lessons, most of pre-service teachers could not enact their lessons within the allocated 80 minutes they had indicated in their lesson plans as per the stipulations of the Ghanaian senior high school physics curriculum document. For example:

- DTB11 used over 114 minutes to complete the lesson on *Structure of the atom* with intervention PSSPL\_2.
- DTB22 rushed through his lesson on *Frictional force* when he realised that he had exhausted 70 minutes of the allocated time and still had a lot to cover. Consequently, learners in his case did not get adequate time to explore the simulation environment comprehensively.
- DTA22 spent the longest time (160 minutes which is equivalent to four periods per the GPC4SHS document) in the delivery of the lesson on *Deformation of solids*.

The Student peers who witnessed the lesson by DTB22 also complained about time as they believed they needed more time than that given to them by the teacher in doing the activities. It was also observed from their activity sheets that most of them did not finish working on the activities because of time. This seemed to indicate that the time factor had limited them in their explorations with the simulation environment in learning the subject matter.

The demonstrative form of inquiry as adapted by DTA2 for the delivery of their lesson was also revealed to be relatively less learner-centred even though it was found to be interactive in nature. This was because the teacher did most of the demonstration during the instruction as the classroom situation adopted for the design of the intervention was such that only the teacher had access to the computer (or simulation environment). Two of the Student peers after witnessing the lesson by DTA2 reiterated that:

If it is based on my experience with the intervention, then I will say that the previous lesson [by DTB2] where we interacted with simulation ourselves was much better ...

This one the teacher demonstrated and he was so fast and since we did not have access, we could not get the concept... but with the other lesson we had access so, even if you

miss it the first time, you can always go back to redo. So, I think the first lesson was more interactive than this because we were doing and seeing for ourselves.

Comments from the learners (Student peers) seem to suggest that the demonstrative approach in itself as led by the teacher was interactive, and that it was the classroom situation adopted where only the teacher had access to the computer (and for that matter, the simulation environment) that posed as a barrier to the instructional process; and hence, seemed to have made the lesson that adopted the demonstrative form of inquiry more teacher-centred as compared to those that adopted the exploratory inquiry where the learners had access to the computers to explore by themselves.

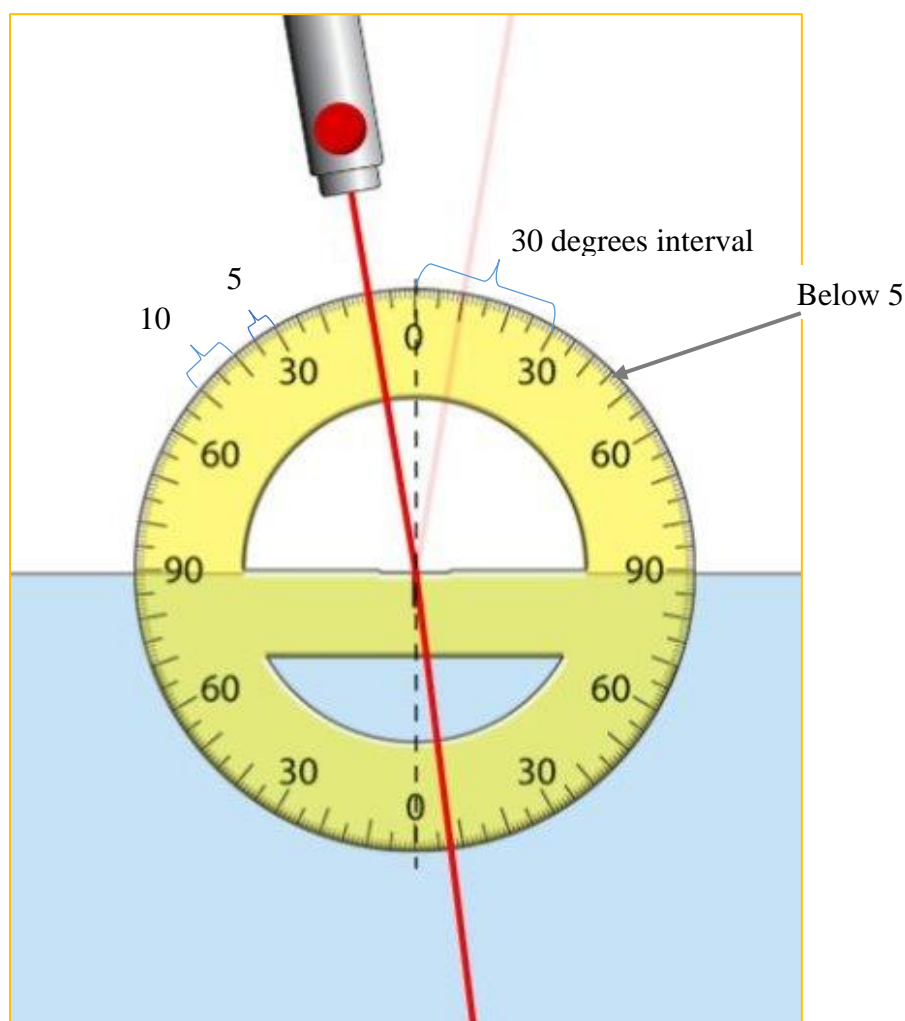
The PhET simulations also had some weaknesses that greatly limited the effectiveness of the interventions developed. For example, two weaknesses were identified in relation to the BL simulation used by DTA1 for teaching the topic: *Reflection and refraction of light*. The first resulted from calibration design of the virtual protractor feature in the simulation environment while the second weakness was identified in the nature of the monochromatic ray of light emitted from the simulation's light source feature. The concerns of the learner group—constituting three of the participating pre-service teachers that assumed the roles of learners during the enactment of the intervention about the virtual protractor were as follows:

Learner 1: ... is about the protractor that we used to measure the angles, we saw that the labelling or the calibration of the protractor is also not very clear. So, it was very difficult for us to measure the exact angle for the angle of incident and the angle of reflection as well as the angle of refraction; that is another weakness.

Learner 2: That was what [learner 1] said about the protractor. So, it was difficult for us to get the exact reading on it.

The learners had genuine concerns pertaining to the virtual protractor (see Figure 4.9) as this was one of shortcomings observed with the BL simulation. The ruler grid on virtual protractor in the BL simulation has a maximum calibration limit of 90 degrees with the minimum being zero degree for each quarter division of the full circle (360 degrees).

Within these limits, clear readings could be observed for angular measurement to be taken at intervals of 30, 10, and 5 degrees below which, the markings on the virtual protractor in the BL simulations are not easily accessible; especially, at intervals of 1 degree (Figure 4.9) where the readings on the protractor seem very blur to an observer/learner. This was the major difficulty encountered on the part of the learners with the simulation interface.



**Figure: 4.9: The protractor feature of the Bending Light PhET simulation.**

The deficiency observed with the virtual protractor seem to have encouraged learners to make fictitious approximations as they could not take accurate readings. This was confirmed by the inconsistencies observed in the values they had recorded on their activity sheets (under Activity 2) during the enactment of both the first and final draft of

the intervention PSSPL\_1. A comparison between the results presented by the facilitators (DTA1) for the angles of refraction in the course of the lesson and that of the learners revealed that majority of the values recorded by the learners as the refracted angle for each given incident angle as shown in Excerpt 4.16 and 4.17 where either extremely below or above the values indicated by the facilitators (i.e., DTA1). Excerpt 4.16 and Excerpt 4.17 are snapshots of the answers provided by the Learner-Group for the lesson on their activity sheet after their exploration of the simulation interface with respect to Activity 2 during the first and second enactment of the PSSPL\_1 lesson respectively.

Incident angle (i°)	Refracted angle (r°)	Sin (i°)	Sin (r°)	$\frac{\sin i}{\sin r}$
10	8°	0.173	0.139	1.245
20	15°	0.342	0.258	1.326
30	21°	0.500	0.358	1.397
40	28°	0.642	0.409	1.569
50	34°	0.766	0.559	1.370

**Excerpt 4.16: Activity results provided by Learner-Group during try-out with first draft of PSSPL\_1.**

Incident angle (i°)	Refracted angle (r°)	Sin (i°)	Sin (r°)	$\frac{\sin i}{\sin r}$
10	7.5° 6.8	0.174	0.118	1.663
20	13.2	0.342	0.228	1.526
30	20° 19.5	0.500	0.339	1.461
40	25.3	0.642	0.427	1.417
50	30.7	0.766	0.520	1.532

**Excerpt 4.17: Activity results provided by Learner-Group one during try-out with the final draft of PSSPL\_1.**

The areas highlighted with the red rectangle show the column for the refracted angle on the learners' activity sheet where the discrepancies were observed in comparison to the facilitators' expected results (area highlighted with a red rectangle in Excerpt 4.16). Evidently, the deepening of ink as well as the cancellations observed in Excerpt 4.17 seem to communicate the possible struggles and uncertainties the learners might have

encountered in coming to a consensus about the values to record per the protractor readings they observed even with the refined intervention. This suggests that the learners still encountered difficulty in taking measurement with the virtual protractor even when they were given the opportunity to do the same activity again using the simulation in relation to PSSPL\_1 intervention. In addition, their results for the refined intervention differed completely from their initial answers during the enactment of the first draft and also, from that provided by the facilitators. For example, in Excerpt 4.16, the corresponding refracted angles recorded for incident angles 10 and 50 degrees were 6.8 and 30.7 degrees respectively. However, in their initial responses per the first draft for these same incident angles, they recorded corresponding refracted angle values of 8.0 and 34.0 degrees respectively. When compared to that given by the facilitators—7.5 degrees for incident angle of 10 degrees and 35.1 degrees for incident angle 50 degrees, it can be said that the values obtained by the learners were not close to that expected by the facilitators. Interestingly, neither the values recorded for the angles of refraction by learners nor their facilitators (DTA1) reflected the calibration capacity of the virtual protractor as the protractor appears to have been restricted in its design to taking reading for only whole numbers; allowing no room for readings in decimal places or significant figures. Consequently, different levels of approximations were used by learners and even the facilitators in their exploration of the protractor measuring instrument of BL simulation to different orders of decimal places. This suggests that neither the facilitators nor the learners could control the learning outcomes with the virtual protractor as it limited them to use their own subjective discretions to guess values for the refracted angles based on the readings that the virtual protractor afforded.

In relation to the second simulation-related weakness identified with the PSSPL\_1 intervention, the following responses were gathered from designers of the intervention during the focus group discussion after the enactment of the first draft:

DTA11: ... the ray emanating from the source of light was relatively thick. So, even if the protractor had accurate calibrations it would have been still a little difficult to get the exact

value [referring to the refracted angle]. So, the ray was very thick. So, it should have been very thin to get the exact value.

DTA12: Mine has to do with the ray; the fact that it is thick; so, when you put the protractor on it [referring to the ray in the simulation environment], it might fully cover two points on the protractor which to you [an observer/ learner], you might think it's just a point so you will use the point. So, I think it must be thin so that we can read the exact mark on the protractor.

The comments from the Design Team seem to hint that, the effectiveness of the protractor in the BL simulation could be highly dependent on how thick or thin the incident, reflected or refracted ray of light appeared. In the case of the BL simulation as the pre-service teachers pointed out, the ray from the light source appeared thick upon exploration of the BL simulation as shown in Figure 4.9. As a result, it does not properly align with the markings of the protractor for accurate reading to be taken. On the other hand, there is no tab on the BL simulation with a feature to help users adjust the thickness of the ray to achieve the “thin ray” that the pre-service teachers suggested. So, it cannot be said for a fact that a thin ray of light emanating from the light source would help eliminate the deficiency in the design virtual protractor as anticipated by the pre-service teachers. The simulation-related weaknesses identified herein could not be resolved with feedbacks gathered from the participants during focus group discussion after the lesson mainly because these were issues that required the competencies of the developers of the PhET simulation. However, an in-depth exploration of the simulation by the teacher to discover the affordances as well as the limitations of the simulation could provide the teacher with valuable insights into various ways to design the lesson activities to overshadow the weaknesses in the PhET simulation environment selected.

### **4.2.3. Research question three (RQ3)**

How can the improvements in teaching using ICTs and enhanced students' learning of physics concepts be understood and/or explained?

Research question three is answered in two parts by looking at how:

1. improvements in teaching using ICTs can be explained and
2. enhanced students' learning of physics concepts can be explained.

#### **4.2.3.1. Improvements in teaching using ICT (PhET simulations)**

A number of themes emerged from both the quantitative and qualitative data to explain the first part of RQ3 (how can improvements in teaching using ICTs be explained). These themes included: pre-service teachers developed TPACK, pre-service teachers' improved content knowledge, and pre-service teachers' developed competencies in the exploration of the PhET simulation environments.

##### **4.2.3.1.1. Pre-service teachers developed TPACK**

A key component of the present study was to track how the pre-service teachers enhanced their technological pedagogical content knowledge (TPACK) in designing and enacting PhET simulations-supported physics lessons (PSSPLs) by use of PhET simulations. As mentioned earlier in this chapter, two cohorts of the pre-service teachers whose competencies were under study worked in teams of two to develop and model their own lessons after the exemplary materials that was designed by the researcher and implemented them in Phase 1 and Phase 2 of the study. The first cohort of four pre-service teachers (with designated IDs: DTA11 and DTA12; DTB11 and DTB12) taught their lessons as microteaching among themselves in two consecutive teaching try-outs in two teams (DTA1 and DTB1 respectively). The second cohort also made up four pre-service teachers (with designated IDs: DTA21 and DTA22; DTB21 and DTB22) taught their lessons as microteaching first, among themselves and then among their peers (i.e., the different group of pre-service teacher who served only as learners in the study) in two

consecutive teaching try-outs in two teams (DTA2 and DTB2 respectively). In answering the first aspect of the RQ3, the pre-service teachers' developed knowledge in developing and integrating ICT-based lessons were tracked and reported using both quantitative (i.e., TPACK self-assessment questionnaire) and qualitative (lesson plan documents, observation, interview and focus group discussions) evidence. The questionnaire was administered twice: before and after the implementation of their designed interventions. Possible answers to an item were scored on a five-point Likert scale (1 = strongly disagree, 2 = agree, 3=not sure, 4 = agree and 5 = strongly agree). A score of 3 and above indicated a positive favourable opinion while below 3 indicated a negative opinion of the pre-service teachers' response. The TPACK self-assessment questionnaire comprised 38 items and they were pre-determined and grouped under seven constructs namely: Technology knowledge (TK), Pedagogy Knowledge (PK), Content Knowledge (CK), Pedagogical Content Knowledge (PCK), Technology Content Knowledge (TCK), Technology pedagogical Knowledge (TPK) and Technological Pedagogical and Content Knowledge (TPACK).

Table 4.8 and Table 4.9 give a summary of the results of the pre-post survey delineated by each cohort of the four pre-service teachers expressed self-efficacy of the TPACK components for both the first and second phases of the study.

Table 4.8: *Results for pre-and post-test mean score responses for TPACK sub-scales (Phase 1).*

	DTA11			DTA12			DTB11			DTB12		
	Pre	Post	Diff.	Pre	Post	Diff.	Pre	Post	Diff.	Pre	Post	Diff.
TK	2.43	3.86	1.43	3.43	3.81	0.38	3.14	3.91	0.77	3.00	4.00	1.00
PK	4.00	3.43	-0.57	3.86	3.71	-0.15	4.29	3.29	-1.00	3.57	3.43	-0.14
CK	4.00	4.00	0.00	4.00	4.40	0.40	3.80	4.00	0.20	3.60	4.00	0.40
PCK	4.20	4.20	0.00	4.00	4.30	0.30	3.80	4.00	0.20	3.70	4.00	0.30
TCK	3.40	5.00	1.60	4.00	4.60	0.60	3.70	4.00	0.30	2.00	4.00	2.00
TPK	3.26	4.71	1.45	4.00	4.71	0.71	4.11	4.70	0.59	3.14	4.71	1.57
TPACK	3.40	4.20	1.80	3.80	4.80	1.00	3.40	4.70	1.30	3.20	4.80	1.60

Table 4.8 indicates that there were appreciable increments between the respondents' pre-and post-survey means for all TPACK sub-scales with the exception of PK for all the pre-

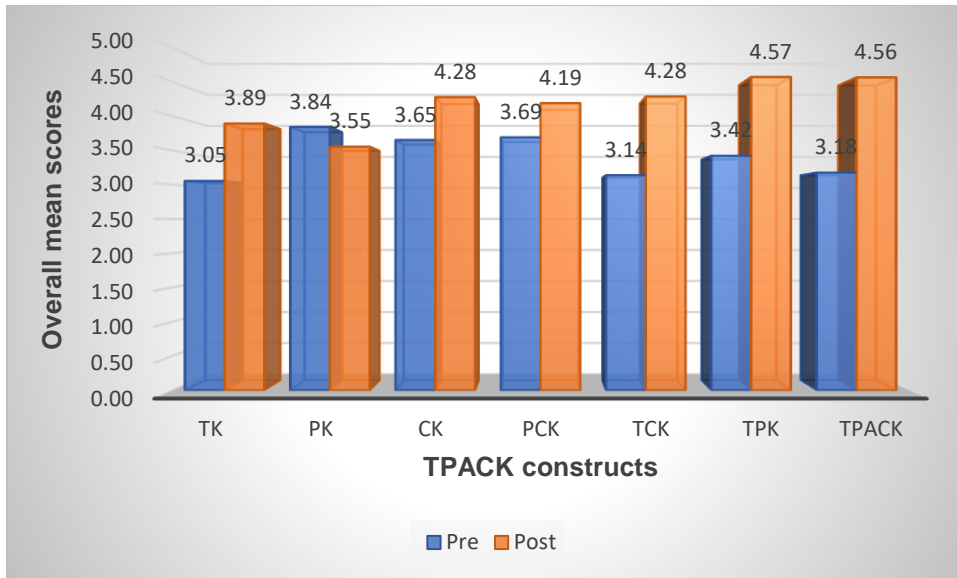
service teachers: DTA11, DTA12, DTB11 and DTB12. The change in PK was actually negative for all the participants (DTA11= -0.57, DTA12=-0.15, DTB11=-1.00, and DTB12=-0.14) suggesting that the pre-service teachers did not expand their knowledge on instructional strategies to teach the subject matter even after the design and implementation of their intervention. The largest area of change between the teachers' pre- and post-survey mean differences as reported by DTA11 was for the sub-scale TCK (1.60), followed by TPK (1.45), TK (1.43), and then TPACK (0.80). For DTA12, it was TPACK (1.00), TPK (0.71), TCK (0.60), and TK (0.38). For DTB11 and DTB12, they were TPACK (1.30), TK (0.77), TPK (0.59), TCK (0.30) and TCK (2.00), TPACK (1.60), TPK (1.57), and TK (1.00) 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 DTA11 and DTB11 reported the same increment for PCK and CK. Similar observations can be made with the pre-service teachers in the second phase (see Table 4.9).

Table 4.9: Results for pre-and post-survey mean score responses for TPACK sub-scales (Phase 2).

	DTA21			DTA22			DTB21			DTB22		
	Pre	Post	Diff.	Pre	Post	Diff.	Pre	Post	Diff.	Pre	Post	Diff.
TK	3.57	3.67	0.10	2.29	4.57	2.28	3.71	3.87	0.16	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	4.20	0.40	2.60	4.60	2.00	3.80	4.60	0.80	3.60	4.40	0.80
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	4.00	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

The only pronounced difference is reported on DTA22 who recorded a gain (0.43) on the PK construct. That notwithstanding, the analyses of all the other constructs followed similar trends as observed from the first study. Thus, the overall results for both Phases (see Figure 4.11) showed marked changes in all components of TPACK with largest areas of change occurring in technology-related sub-scales: TPACK (gain=1.39), TPK (gain = 1.15), TCK (gain = 1.15), and TK (gain = 0.84). This is an indication that the pre-service

teachers developed their technology integration knowledge and skills in the technology-related sub-scales much better as they might have perceived them as new knowledge; The next sub-scale with the highest change was CK (gain = 0.63). The results indicate that the pre-service teachers might have initially over-rated their CK as high, however, they might have expanded their knowledge about the physics concepts after the intervention not because it was new, but because they realised they did not yet completely understand these concepts. The gain in PCK (0.50) reported was fairly low, but more surprisingly was the change (gain=-0.29) observed with the pre-service teachers' PK. This is an indication of a loss in the pre-service teachers' pedagogical knowledge after the intervention. Thus, the results seem to suggest that the intervention did not help the pre-service teachers to expand their own knowledge of instructional strategies in teaching their subject matter. A possible reason for the relative loss in the pre-service teachers' PK could have been the difficulty they might have encountered in assessing their own abilities needed to design and enact PhET-simulation-based lessons. Apparently, the pre-service teachers initially rated themselves high on the PK scale because of their perceived understanding of PK; which they might have misconstrued to be purely teacher-centered way of teaching. This suggests that the pre-service teachers might have been deeply rooted in the teacher-centered teaching approaches which might have influenced their thinking and teaching practices. While this was not the case with the technology-related sub-scales which they perceived as new; they basically realised that PK (and even PCK) were also new after experiencing the intervention with the PhET simulations. Figure 4.10 gives a summary of the results of the respondents' pre- and post-survey means for all seven TPACK sub-scales for both phases of the study.



**Figure 4.10: Pre- and Post-survey means for TPACK sub-scales for Phases 1 and 2.**

As observed with the results from the quantitative data, the pre-service teachers developed their knowledge and skills (TPACK) for integrating ICT (simulation) into the teaching of high school physics. Various constructs of the TPACK framework (especially the technology-related ones) were evident in the lesson plan documents the pre-service teachers developed as part of the PhET simulations-based interventions which suggested that their teaching had improved by use of the PhET simulation. For example, the lesson plan documents which were designed by Design Teams DTA2 and DTB2 for teaching the topics: *Deformation of solids* and *Frictional force* respectively showed evidence (see Excerpts 4.18 and 4.19) of how the pre-service teachers developed their competencies for teaching high school physics in an improved manner. Excerpt 4.18 illustrates how the pre-service teachers’ (in DTA2) developed TPACK informed their teaching with the *Hooke’s Law* PhET simulation environment. The pre-service teachers in DTA2 used their knowledge of the affordances of the simulation environment (entitled: *Hooke’s Law*) (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 concepts in physics (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 their way of teaching in a manner that is interactive and activity-oriented (i.e., making use of their TPK).

<p style="text-align: center;"><b>TPACK</b></p>	<p><b>Activity 2:</b> How applied force influences displacement (25minutes).</p> <p>This activity is geared towards investigating Hooke's Law using the PhET simulation – <i>Hooke's Law</i>.</p>	<p style="text-align: center;"><b>TK</b></p> <p>Students observe teacher or colleague student as he/she explores the simulations through demonstration with respect to the outlined guidelines by the teacher in order to define spring force; write an equation for both forces; predict how applied force affects displacement but differs from spring force; and then show mathematically the relationship between applied force, spring constant and displacement as well as answer the questions under <i>activity 2</i> on the activity sheet based on prior as well as newly acquired knowledge and experiences with the simulation environment.</p> <p style="text-align: center;"><b>TPK</b></p> <p style="text-align: center;"><b>TCK</b></p>
	<p>By setting the simulation environment such that the boxes in the <i>indicator column</i> beside values, applied force, spring force, displacement and equilibrium were marked, and spring constant value is kept at constant value of 100N/m,</p> <p>teacher guides students through demonstration to do the following in groups:</p> <ul style="list-style-type: none"> <li>❖ observe the values of the displacement and spring constant in relation to how they both equal to spring force, in order to</li> </ul>	
	<p>define spring force in their own words mathematically (in <i>activity 2</i> on activity sheet), when applied force value is set at:</p> <ul style="list-style-type: none"> <li>• 50N</li> <li>• 100N</li> </ul> <ul style="list-style-type: none"> <li>❖ observe and compare the values of applied force to spring force in order to write an equation for both forces (as answer to question under <i>activity 2</i> on the activity sheet) when the applied force value is altered using the applied force slider</li> </ul>	

**Excerpt 4.18: Illustrations of the pre-service teachers' (in DTA2) developed TPACK.**

Similarly, the pre-service teachers in DTB2 also made use of their developed TPACK in a way that shaped their teaching practices for the better as depicted in Excerpt 4.18.

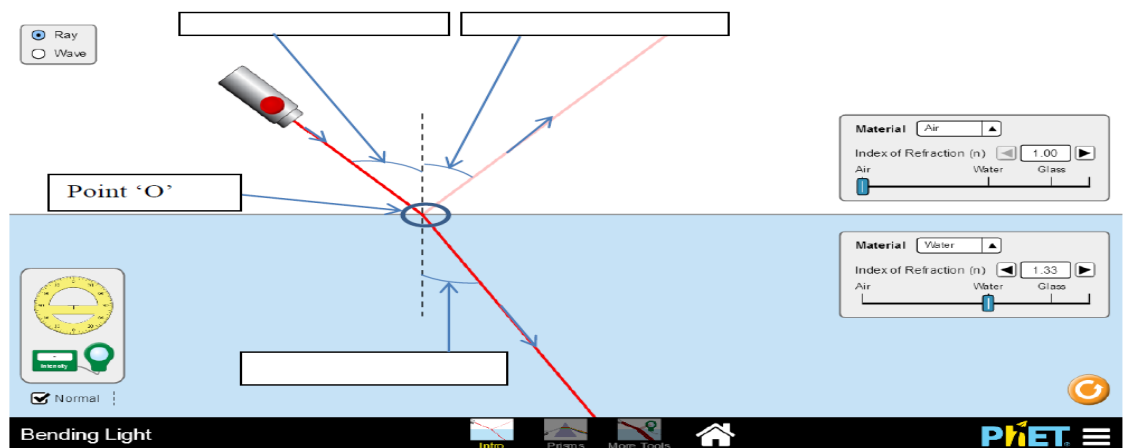
Main Activities	<i>Activity 1: Definition of frictional force (25 mins.)</i>	
	TPK	<p>For students to come out with the definition of frictional force in their own words, the teacher puts them in groups of three and guides them to perform the following activities:</p> <ul style="list-style-type: none"> <li>• use a snapshot from the simulation environment to help students set up their simulation for activity 1</li> <li>• explore the simulation for five minutes</li> </ul>
	TK	<ul style="list-style-type: none"> <li>• observe the simulation on friction as they do the exploration</li> </ul>
	TCK	<ul style="list-style-type: none"> <li>• identify the arrows X and Y on the body of mass 50kg as explored in the simulation</li> <li>• record the values of X and Y as shown on the activity sheet.</li> </ul>
	TCK	<ul style="list-style-type: none"> <li>• explain why the body of mass, 50kg did not move when the force X was applied on it</li> </ul>
	TCK	<ul style="list-style-type: none"> <li>• identify the nature of the surface of the floor in contact with the body of mass 50kg as explored in the simulation</li> <li>• define frictional force in their own words</li> </ul>
		<p>Using the snapshot on the activity sheet as a guide, students set the simulation environment as guided by the teacher in order to define frictional force.</p> <p style="text-align: center;"><b>TPACK</b></p>

**Excerpt 4.19: Illustrations of the pre-service teachers' (in DTB2) developed TPACK.**

Elements of Excerpt 4.19 were developed based on the PhET simulation entitled: *Forces and Motion: Basics (Friction)*. It can be observed from the evidence depicted in Excerpt 4.19 that, the pre-service teachers in DTB2 used their understanding of the interactive features of PhET simulation (i.e., making use of their TK) in ways that helped them 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); guide learners to explore and manipulate the 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). Similar evidence in these regards can be observed in the lesson plan documents developed by the other pre-service teachers in Design Teams DTA1 and DTB1; see APPENDIX F for sample coded lesson plan documents.

The results that the pre-service teachers developed their TPACK was also confirmed during the microteaching sessions with the various ICT-based lessons developed by each Design Team. For example, in an observation of DTA11's lesson on the topic: *Reflection and Refraction of light* by use of the PhET simulation entitled: *Bending Light*, DTA11 demonstrated his developed TPACK as he did the following:

- allowed the learners to explore the simulations environment in groups for some few minutes at the beginning of the lesson in order to make sense of the affordances of the *Bending Light* (BL) PhET simulation environment (by this DTA11 demonstrated TPK),
- projected a snapshot of the BL simulation with some few additions (in the form of rectangular boxes and arrows, as shown in Figure 4.11.) on the board by use of a projector (by this action DTA11 demonstrated TCK as well as TPACK),
- instructed his learners to identify what concept in physics the features of the simulation indicated by the arrows represented (by this action, DTA11 also a demonstration of his TPACK).



**Figure 4.11: First interface for the Bending Light (BL) PhET simulation with additions made by DTA1.**

By these few actions, it was evident that the teaching approach adopted by DTA11 was learner-centred and also, reflective of his apparent developed TPACK in that he used a

snapshot from the BL simulation as a guide to draw learners' attention to the subject matter of interest as depicted in Figure 4.11: the directions of the incident, reflected as well as the refracted rays, the various angles that the incident, reflected, and refracted rays make with the normal as well as the point of incidence (labeled "point O" on the snapshot, Figure 4.11). In addition, DTA11 guided the learners to identify the functions of some of the elements in the simulation environment based on their prior knowledge on the concept, *Reflection and Refraction of light*. This was a clear indication that his TPACK had developed.

The pre-service teachers also reiterated during an interview with them after the design and implementation of the intervention that their teaching had improved because of their developed TPACK. Five of them indicated the following:

DTA11: I think I never knew about simulations until the workshop. So, it helped me by even making my work easier and by using the simulation to be able to teach my content [TCK].

DTB12: ... 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].

DTA12: 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 on that particular topic...[TPACK].

DTB11: I played the role as a facilitator, I guided them to use the simulation [TPK].

DTB21: As someone who was not actually having ICT 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 it to direct me towards the various steps that I should observe in my teachings [TPK].

Feedbacks given by the pre-service teachers during the focus group discussions after each microteaching try-out sessions where the participating pre-service teachers taught among themselves with the PhET simulation-based interventions also showed that the pre-service teachers had improved their teaching practices subject to their developed TPACK. This reflected in the suggestions that the pre-service teachers gave to their colleagues (whose lessons were enacted) in their response to the question: “What can be done to improve the simulations-based intervention designed and enacted by your colleagues”. For example after DTA1’s first teaching try-out with their PhET simulation based intervention (on the topic: *Reflection and refraction of light*), the following were the suggestions given by their colleagues from DTB1:

DTB12: May be after allowing us to explore the simulation environment [TPK], he [referring to DTA11] should have explained to us what we were asked to observe, the meaning of what we observed, and then, the way we are going to use the simulation itself to achieve the goal that he set [TPACK] .

DTB11: I thought that in the course of directing us to work with the simulation, ...the teacher should have also projected the simulation after we were done with the activities [TPK]. At least, he should have also followed the same, for example, if he asks us to do for 10 degrees, he should also show us for the sake of those who could not do it.

#### **4.2.3.1.2. Pre-service teachers’ improved content knowledge**

Another way we can explain improvements in teaching realised with the PhET simulation is perhaps in the pre-service teachers’ improved content knowledge. At the beginning of the initial workshop, it was observed that some of the pre-service teachers had difficulties in explaining certain concepts in physics. However, after the design and implementation of the intervention, they seemed to have gained much understanding into the same concepts and thus, could explain those same concepts better in a way that improved their teaching with the ICT (simulations)-based lesson artefacts. Interview data gathered confirmed this finding. For example, the pre-service teacher with the designated ID,

DTB22 shared his sentiment about how his teaching improved with the PhET simulations by making a comparison between the way he used to teach the concept, *Friction* in abstraction with the way he can currently teach the same concept using the PhET simulation because he had developed his conceptual understanding about *Friction*. He had the following to say during the interview:

When I chose the topic friction, I remembered that I had taught this topic [Friction] before in the 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 the SHS classroom, they don't 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 does not demand much at that time. So, as a teacher, I had to try with all that I could do for the students in order help them to 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 they will get much understanding than what I used to give...

The foregoing comments suggest that the DTB22 lacked conceptual understanding of the concept *Friction* before participating in the study; as a result, he could not give concrete examples of how *Friction* could apply in the real-world during his previous teaching. Apparently, this was a limitation to his teaching of the concept as he resorted to teaching the topic in abstraction without understanding. However, with the use of PhET simulations, it appears that his understanding of the subject matter enhanced and consequently, helped him to explain the concept and its application better. The presentation slides (Excerpts 4.20a and 4.20b) developed (using Microsoft PowerPoint presentation software) by the DTB22 for providing summaries to the activities (see Excerpt 4.20c) designed on the concepts he taught under the topic: *Frictional force* during the delivery of his Design Team's PhET simulation-based lesson confirmed the statements he made in the interview.

## Summary of Activity 2 key points

12

### Observations after increasing the applied force to 75N

The body moves after increasing the applied force

- ▶ The speed of the body also begin to increase

### Observations after moving the friction slider closer to Lots

- ▶ The speed of the body begins to decrease
- ▶ The force of friction also increases
- ▶ The force of friction is also greater than the applied force
- ▶ The force of friction is equal to the applied when the body comes to rest

### Effects of frictional force

- ▶ It decreases the speed of a moving body
- ▶ It prevents bodies from moving.

### Excerpt 4.20a: Summary of Activity 2 as designed by DTB2.

Excerpt 4.20a shows the explanations given by DTB22 in explaining the key concepts on the “Effects of frictional force” to his learners in response to the PhET simulation-based tasks they designed for Activity 2 (see tasks for Activity 2 in Excerpt 4.20b) as part of the simulation-based lesson on the topic, *Frictional force*. This was a confirmation of DTB22’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 Excerpt 4.20b that not only was DTB22 able to explain the concept of *Friction* better after the design of the PhET simulations intervention, but also he was equipped based on his improved content knowledge to guide his learners 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 PhET simulations-based lesson. The results here corroborate that from the quantitative data for the TPACK self-assessment survey (see Table 4.8) which reported a CK mean score of 3.60 for DTB22 before the intervention and 4.40 after the intervention—suggesting that DTB22 had improved his content knowledge owing to the PhET simulations-based intervention.

**Solution to the applied question**

**Applications of frictional force**

- (a) It makes braking action of vehicles possible
- (b) It is applied in the sharpening of cutlasses
- (c) It keeps the feet from sliding during walking


**Excerpt 4.20b: Summary of real-life application aspect of Activity 2 designed by DTA2.**

*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.

.....

.....

.....

(c) 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.

- (1).....
- (2).....

**Excerpt 4.20c: Activity 2 as designed by DTB2.**

Similar evidence was observed with pre-service teachers in DTA2, DTB1 and DTA1 which explained the improvements in their way of teaching in relation to the topics: *Deformation of solids*, *States of Matter* and *Reflection and Refraction of light* respectively as they were also able to explain the physics concepts pertaining to their chosen topic better after the design and implementation of their respective PhET simulation-based intervention than before the intervention.

#### **4.2.3.1.3. Pre-service teachers' developed competencies in the exploration of the PhET simulation environment**

Results from the qualitative data revealed that the pre-service teachers developed their knowledge and skills for exploring the PhET simulation environments during the professional development arrangement; as for most of them, the first time they heard or came into contact with simulations was during the professional development arrangement. 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 the PhET simulations-based lesson artefacts and their preparations prior to the implementation of their respective interventions helped them to uncover the rich potentials of the 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 the PhET simulation ICT tool. This was confirmed by the pre-service teachers during the interviews conducted after the implementation of their respective PhET simulations-based lessons. Three of the pre-service teachers in the first phase of the study responded to the question, "What informed your preparations for teaching this simulations-based lesson in an interactive way?" as follows:

DTA11: ... I had to work on interacting with the simulations that I wanted to use in order to understand it better.

DTB12: I think I had to explore the simulations environment myself in order to know much, to be well versed in it ...

DTA12: First, to teach this topic well, I looked at the topic and then, I downloaded the simulations that could best teach the topic, after that, I explored the simulation to see what I can use the simulation to teach on that particular topic...

In the focus group discussion with the second cohort of pre-service teachers (Phase 2), the pre-service teachers also had similar dispositions as they described their experiences with the PhETs as the medium through which they taught effectively—placing emphasis on how their exploration of the simulation environment contributed to improvements observed in their teaching practices with the intervention:

DTA21: Without exploring the simulation, it is very difficult for the teacher to use it [simulations] in teaching. The reason being that we didn't know how to teach or manipulate the various features of the simulations until we explored it many times.

DTB22: 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 students to 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.

DTA22: It is one thing having the content, and another thing to explore the simulation in order to know what the simulation features do. This is more like a practical session where you are able to know what does what and where an apparatus has to 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 to teach 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 can't and what it can before you go in to use it in the classroom...

DTB21: When you explore the simulation, you are able to 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 the pre-service teachers (for both the first and second phases of the study) suggest that through their developed knowledge and skills in the exploration of the PhET simulation environments, they gained deeper understanding into the affordances of the PhET simulations, identified weaknesses in the PhET simulations (as observed under results for RQ2) and in addition, became informed about the strategies to adopt in order 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 effective (i.e., interactive) with the focus on the learner.

It is important to mention that, the competencies the pre-service teachers gained in the exploration of the PhETs as highlighted herein, seemed to have been driven by: 1) certain components of the professional development arrangement that were used as scaffold for grooming the pre-service teachers into developing their competencies in using ICT(simulation) for the teaching of high school physics in an interactive manner; and 2) their sufficient content knowledge especially, at the beginning of the PDA. In relation to the former, results from the interview data gathered from the pre-service teachers for both Phases 1 and 2 of the study revealed that the initial training workshop considered at the beginning of PDA formed the basis for the improvements in teaching realised with pre-service teachers as a consequence of their developed competencies in the use and exploration of the PhET simulations. The following comments were the responses from three of pre-service teachers from both phases of the study in response to the question, "How did the initial workshop influence your way of teaching in your exploration of the PhET simulation?":

DTA12: 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.

DTA22: 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.

DTB11: ... this workshop has helped us to use and explore the simulation or the technology effectively in our teaching. We realised through the exploration that we can involve the students whereby the dimensions that we were taught in the workshop has to be in our teaching when using the TPACK. So, we realised that the authenticity, the group discussion or collaboration and those things were present unlike our normal way of teaching which is more or less teacher-centred.

All the comments made suggest that through the initial training workshop, the pre-service teachers became knowledgeable about simulations and its use as a technological and instructional tool for teaching in an interactive manner—an indication that the two theories: TPACK (Mishra and Koehler, 2006) and the five dimensions for meaningful learning with ICT (Howland et al., 2012) that the pre-service teachers were exposed to during the initial workshop of the PDA facilitated their developed technology knowledge. In addition, the focus group discussion with the pre-service teachers revealed that the team work arrangement (i.e., the Design Team approach) employed during the initial workshop helped the pre-service teachers in developing their competencies in exploring the simulation environment in order to discover its potentials in ways that improved their teaching. The following were the comments the pre-service teachers (in Phase 2 of the study) made in this regard:

DTA21: ... working together, actually, one person is not having all knowledge. So, working together helped us to share ideas on the simulation feature in making them either concrete or more understandable to us ...

DTA22: 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 ...to understand it best.

DTA22 further explains using his experience with the PhET entitled: *Hooke's Law*:

Also, with the Hooke's law, you will realise 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, it could be that the other person will be checking out to see if 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 sims to teach the content in a better way.

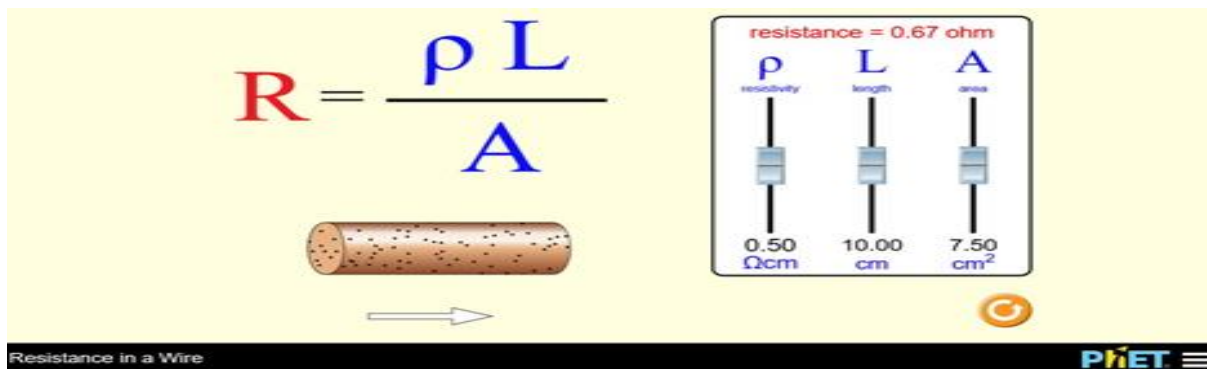
DTB21: ... as a group, we shared ideas and by adjusting the various buttons, we were able to see the various demonstrations that we are expecting the students to observe. So, the group work actually helped us in discussing and understanding more about the various buttons of the simulation.

DTB22: When one person is exploring it, you may think that what you are exploring is actually the right thing, but when there is another person there checking what you are doing, or watching or helping out, the person can be able to pinpoint certain holes and say let us do it this way. So, with that, we come out with an agreement that this would be the best.

In relation to the later, it was observed at the beginning of the initial training workshop (PDA) that the pre-service teachers, for example, DTA11 and DTA12 who constituted Design Team DTA1 for the first phase of the study had sufficient content knowledge; this confirmed their perceived high CK (i.e., 4.00 and 4.00 respectively) before the intervention as observed with the results from self-report TPACK pre-survey data collected. Apparently, their sufficient content knowledge facilitated their exploration of the 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 initial workshop where the first

cohort of pre-service teachers were tasked to:1) explore a PhET simulation of choice under the high school physics section on the 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 sim, and 4) explain how the selected PhET simulation represented the objectives identified. To achieve tasks 2 and 3, the pre-service teachers were expected to present their feedbacks pertaining to Tasks 2 and 3 on Power Point presentation slides (Excerpts 4.20a and 4.20b) 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, the PhET simulation entitled: *Resistance in a Wire* (denoted as RW, see Figure 4.12) was chosen by DTA1.



**Figure 4.12: *Resistance in a Wire* (RW) PhET simulation environment.**

In response to Tasks 2 and 3, Excerpts 4.21a and 4.21b show evidence of the feedback given by DTA1 using Power Point presentation software.

**PHYSICS**  
**Electricity and magnetism**  
**Direct current circuit analysis**  
**(Resistance)**

**LESSON OBJECTIVES**

By the end of the lesson, students should be able to:

- i state the factors that affect the resistance of a conductor
- ii explain how each of the factors affect resistance

**Excerpt 4.21a: Response to Task 2**

**Excerpt 4.21b: Response to Task 3**

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 students. This explains the information presented on the slide by DTA1 as shown in Excerpt 4.21a— suggesting that the pre-service teachers in DTA1 were specific in selecting a topic to be used with the *RW* PhET simulation environment. In addition, Excerpts 4.21a and 4.21b confirm that the pre-service teachers in DTA1 were able to uncover the affordances of the *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 with the corresponding learning objectives.

When asked about what informed their choice of objectives (in response to task 4) as indicated in Excerpt 4.21b, one of the pre-service teachers in DTA1 with ID, DTA12 explained as quoted:

When we set the tab on the various elements [*referring to the sliders associated with resistivity,  $\rho$ ; 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 DTA12 suggests that the pre-service teachers in DTA1 had a clear understanding of the concepts that the *RW* simulation and its interactive interface mimicked because of their seemingly sufficient content knowledge. Therefore, they were able to easily demonstrate how the concept, “Resistance” was represented by the *RW* simulation in relation to the length,  $L$ ; cross-sectional Area,  $A$ ; and the material property (resistivity,  $\rho$ ) of a cylindrical conducting wire. Results shown here affirms that sufficient content knowledge on the part of the pre-service teachers (before the intervention) served as basis for their developed competencies in the exploration of the PhET simulation environment.

The results presented herein addressed the first part of research question three by showing that the pre-service teachers improved in their teaching practices using ICT (i.e., PhET simulations) because of their developed TPACK, improved content knowledge and developed competencies in the exploration of the PhET simulation environments. However, the road to realising improvements in their teaching was not without challenges:

1. Some pre-service teachers had difficulties with the exploration of the PhET simulation environment itself in discovering its affordances. A typical example was observed with DTB1. The pre-service teachers in DTB1 struggled in the exploration of the first simulation environment (entitled: *States of Matter*, denoted as *SM*) they chose during a preliminary exercise given by the researcher (at the beginning of the PDA) prior to their actual design and implementation of the ICT-based interventions. Their difficulty apparently was as a consequence of their insufficient content knowledge. During the preliminary exercise, the pre-service teachers (DTB1) were tasked to: (a) outline possible learning objective from the GPC4SHS that best aligned with the affordances of the *States of Matter* PhET simulation environment and (b) explain how the affordances of the simulation could be explored in order to achieve the objectives they identified in task (a). In response to task (a), they mentioned that the *SM* simulation could be used to differentiate between the three phases of matter (i.e., solid, liquid and gas). In response to task (b), they seemed confused about the specific feature of the simulation they needed to explore to bring about the differences they sought.

Consequently, they attempted interacting with all the features in the *SM* simulation environment, but seemed not to comprehend what the simulation's responses to their explorations implied. It was obvious as observed during their interaction with the *SM* simulation that the two pre-service teachers (in DTB1's) lacked conceptual understanding of the various states of matter and their respective properties, as a result, they could not engage their prior knowledge to discover the affordances of the *SM* simulation.

2. All the pre-service teachers also had difficulties in establishing a relationship between the physics content, teaching strategies and the affordances they had discovered with the selected simulation environment to inform the development of the simulations-supported lesson artefacts. This was confirmed by the interview with some of the pre-service teachers. When asked the question: "What were your challenges during your preparations with the PhET simulation during the design of the intervention?". The following were their responses:

DTB22: ... I had a little problem during the preparation because initially even when you introduced us to the PhET simulation, I didn't understand much about the simulation although you will see that they [referring to the developers of the PhET simulations] have named the various simulations, but then, how do you use this to teach? was a challenge. So, that was the major problem I faced.

“

DTA22: ... during the preparation, something that I had realised 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 don't know how to use it or strategise it into the content, you will have a problem. That was what made us struggle a lot in our group [Design Team]. 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.

DTA12: I think how to instruct them to use the simulations to actually solve the question on the activity sheet for me was difficult at the beginning.

Responses from the three pre-service teachers suggest that not only were they lacking in their TPACK at the initial stages of the design, but also their knowledge of using the PhETs to represent concepts in physics (TCK) as well as knowledge of how to use simulations for teaching in a manner that is interactive and activity-oriented (TPK) seemed not well developed for effective design of the 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 the PDA. This corroborates results from the TPACK pre-survey where the overall mean scores as reported by the pre-service teachers before the design of the interventions for their TK, TCK, TPK, and TPACK seemed low—indicating that they did not perceive themselves to have sufficient competencies in these domains.

3. A difficulty in shift from the traditional approach of teaching to a learner-centred way of teaching physics also posed as a challenge for the Design Teams. This was evident in observations made by the researcher during the delivery of the first lessons (before the actual intervention) that the pre-service teachers designed at the beginning of the PDA. It was observed that almost all the pre-service teachers used the simulations to teach in a purely traditional manner; where they dominated the instructional process by imparting the knowledge of the physics concepts instead of creating an atmosphere for students to construct their own knowledge based on their experiences with the simulation. Interestingly, the teacher activities they enlisted for these preliminary lessons before the design of their respective interventions seemed to depict a learner-centred approach though they adopted a purely teacher-centred approach for the delivery of the lessons.

#### **4.2.3.2. Enhanced students' learning with ICT (PhET simulations)**

Another aspect of the research question three was to explain how enhanced students' learning of physics concepts was realised with the PhET simulation-based intervention. In answering this question, both qualitative and quantitative evidence were used. These

helped to explain the enhanced students learning of the subject matter at two levels: improved students learning outcomes and Student peers' perceived positive experiences with the PhET simulation-based intervention respectively. The quantitative data included pre- and post-test and the questionnaire on Student peers' experiences with teaching try-out while the qualitative data resulted from focus group discussions with Student peers during Phase 2 and Student peers' responses to items on the pre-and post-tests.

#### **4.2.3.2.1. Improved students learning outcomes (ISLO)**

A pre and post- test (see APPENDIX D (D4 and D5)) consisting of the same items on the topics: *Deformation of Solids* (DOS) and *Frictional Force* (FF) that were conducted before (pre) and immediately after (post) each of the two lessons (DOS by DTA2 and FF by DTB2) was implemented. These two lessons were the lessons conducted during the second try-out for the second phase of the study in which a member of each Design Team (i.e., DTA22, and DTB22 respectively) taught the lessons they designed among nine (9) Student peers after it had been enacted in a microteaching first try-out session. For each of the lessons, the test was developed by the Design Teams, and reviewed by the researcher, and aimed at determining the Student peers' learning outcomes for the respective lessons. The tests were made up of five (5) items for each lesson. They were scored out of 10 and scaled down to 5. A mean score of 3 and above is a positive and favourable score while a mean score below 3 is a negative and unfavourable outcome.

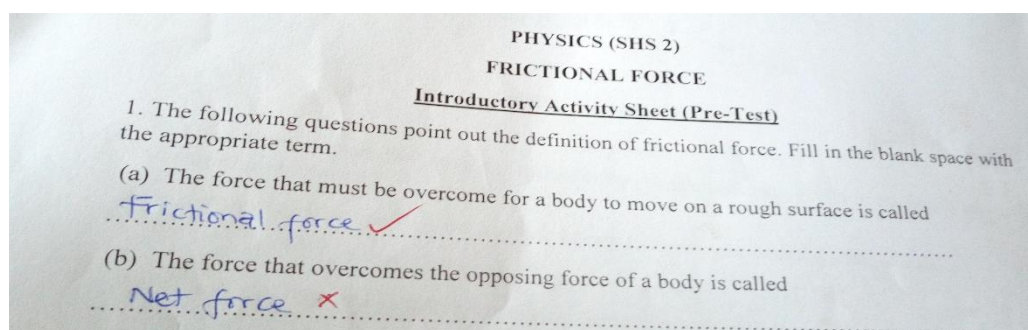
Table 4.9 gives an overview of the results of the pre-and post-test scores of the Student peers. Table 4.10 indicates that the test scores for the lesson on *Deformation of Solids* (pre=2.67, post=3.33) were lower compared to that on *Frictional Force* (pre=3.33, post=4.00). However, the mean gains (Deformation of Solids=0.66, Frictional Force=0.67) were about the same for both lessons, an indication that the impact of the intervention was similar in both lessons.

Table 4.10: Pre- and Post -test mean scores of Student peers' learning outcomes

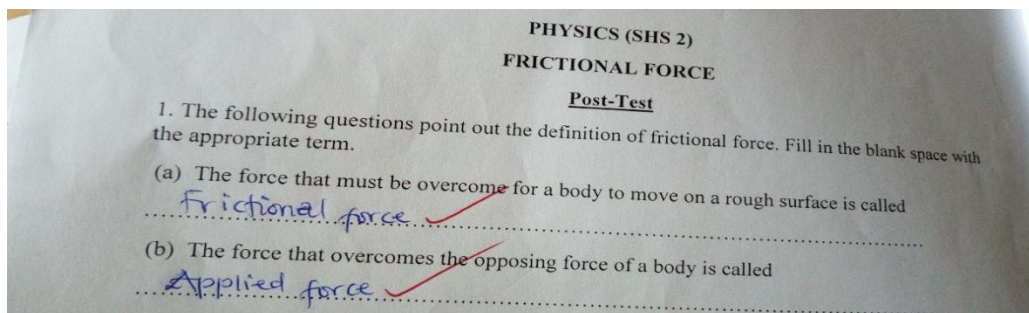
	Deformation Solids DTA2 (N=9)	of Frictional Force DTB2 (N=9)	Overall (N=9)
Score for Pre-Test	2.67	3.33	3.00
Score for Post-Test	3.33	4.00	3.67
Mean Gain	0.66	0.67	0.67

A possible reason which explains the relatively low scores for the lesson on DOS could have been the difficulty level of the subject matter. That notwithstanding, the overall difference between the means (0.67) gives an indication that the PhET simulation-based lessons impacted positively on the students' outcomes.

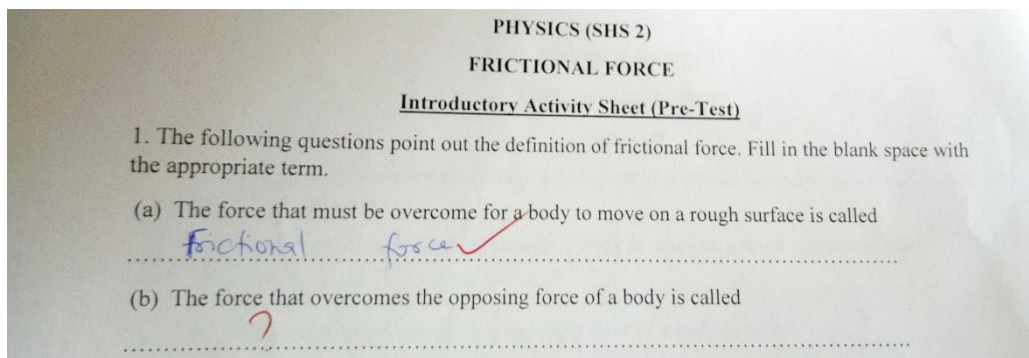
The analyses of responses given by Student peer 3 and student peer 6 in answering the pre- and post- test items for the lesson on *Frictional force* confirmed the quantitative results (see Excerpts 4.22a and 4.22b; Excerpts 4.23a and 4.23b for student peer 3 and student peer 6 respectively).



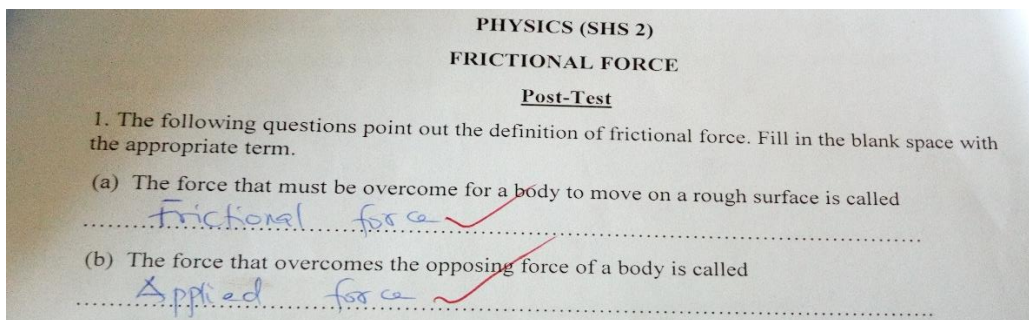
**Excerpt 4.22a: Snapshot of student peer 3's responses to the pre-test items (i.e., question 1) before the lesson on the topic: Frictional force.**



**Excerpt 4.22b: Snapshot of student peer 3's responses to the same test (post-test) items (i.e., question 1) after the enactment of the lesson on the topic: Frictional force.**



**Excerpt 4.23a: Snapshot of student peer 6's responses to the pre-test items (i.e., question 1) before the enactment of the lesson on the topic: Frictional force.**



**Excerpt 4.23b: Snapshot of student peer 6's responses to the post-test items (i.e., question 1) after the enactment of the lesson on the topic: Frictional force.**

The results from Excerpts 4.22a and 4.23a show that before the lesson was enacted with the simulation-based lesson on *Frictional force*, all the two Student peers (i.e., Student

peer numbers 3 and 6) could not answer the question 1(b): “The force that overcomes the opposing force of a body is called...” (It would be envisaged that since these Student peers are pre-service teachers who will be graduating soon to teach this same content at the SHS levels, they would have mastered these concepts by now). It appears that Student peer 3 had misconstrued *Applied force* to mean *net force* as seen in Excerpt 4.7a. An indication that there were gaps in his prior knowledge about *Frictional force*. Student peer 6 seemed not to have any prior knowledge about it as he left the space blank. However, after the PhET simulation-based lesson, they all answered the same question correctly as indicated in Excerpts 4.22b and 4.23b. These suggest that the intervention helped the Student peer 3 to clear his misconception about the name of the force that overcomes the opposing (frictional) force. Also, Student peer 6’s knowledge gaps about frictional force were filled. This is an indication (as found with the quantitative results), that the PhET simulation-based lesson impacted positively on the students’ learning outcomes; thus, their learning had been enhanced using the ICT (simulations).

Results from the focus group discussions with the Student peers after the implementation of the two lessons: *Deformation of Solids* and *Frictional Force* also confirmed this finding. In relation to the lesson on *Frictional force*, the Student peers believed that with the PhET simulation entitled: *Force and Motion: Basics (Friction)*, they learned and understood the concepts under the topic: *Frictional Force* better— suggesting that learning was enhanced because their learning outcomes in relation to the topic had improved. The following were the responses gathered from two of the Student peers in this regard:

Student peer 2: ... at first when they teach us, they tell us that for a body to be able to move, the applied force must be greater than the frictional force; that one it was just an abstract thing, but today with the simulation, it was concrete, we saw it clearly that the body was able to move by increasing the applied force [ISLO].

Student peer 7: The simulation with respect to the topic selected was appropriate because today, I got to know that frictional force can also be called retarding force [ISLO].

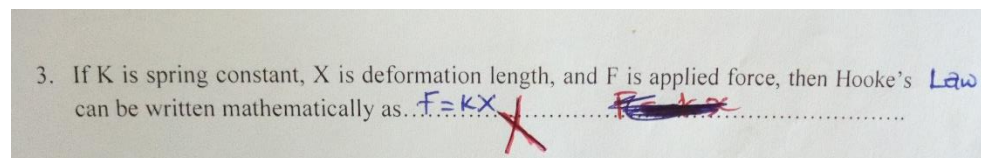
Comments as highlighted by the Student peer 2 and Student peer 7 suggest that the use of the PhET simulation in the instructional process enhanced their conceptual understanding and expanded their knowledge of *Frictional force*—an indication that their learning with the PhET simulation had been enhanced.

Similarly, with the lesson on *Deformation of Solids* by DTA2, the Student peers believed their learning had been enhanced because their learning outcomes had improved in relation to the implication of the mathematical expression for the physics concept, *Hooke's Law* which in terms of springs; states that “*the force needed to extend or compress a spring by some distance is proportional to that distance*”. Two of the Student peers explained their improved learning outcomes in this regard as follows:

Student peer 1: Considering the mathematical expression of the force; I mean the applied force in relation to the spring constant and then displacement. Initially I did not find the negative sign so important ..., but later on, I observed from the simulation that the restoring force was acting opposite to the applied force. So, the negative sign is very important. I think I have learnt something new.

Student peer 8: ... like as somebody [peer 1] was saying that he now knows the essence of the negative sign. At the SHS, me for instance, learning Hooke's Law was like “chew and pour” [meaning, rote learning] but then I did not know the essence of the negative sign until when we started with the simulation.

The comments by Student peers 1 and 8 were confirmed in their respective test papers before and after the intervention with the *Hooke's Law* PhET simulation lesson designed by DTB2. See Excerpts 4.24a and 4.24b; and Excerpts 4.25a and 25b.



**Except 4.24a: Snapshot of Student peer 1's response to pre-test item number 3.**

3. If K is spring constant, X is deformation length, and F is applied force, then Hooke's Law can be written mathematically as  $F = -kx$  ✓

**Except 4.24b: Snapshot of Student peer 1's response to post-test item number 3.**

3. If K is spring constant, X is deformation length, and F is applied force, then Hooke's Law can be written mathematically as  $F = k(x)$  ✗

**Except 4.25a: Snapshot of Student peer 8's response to pre-test item number 3.**

3. If K is spring constant, X is deformation length, and F is applied force, then Hooke's Law can be written mathematically as  $F = -k(x)$  ✓

**Except 4.25b: Snapshot of Student peer 8's response to post-test item number 3.**

Results from both the focus group discussion data and the answers given by the same Student peers (numbers 1 and 8) show that the PhET simulations-based lesson on DOS, helped the Student peers to make meaning of the negative sign in the *Hooke's law* mathematical expression. As can be inferred from Excerpts 4.24a and 4.25a, both students omitted the negative sign in their mathematical expressions for *Hooke's law* before the intervention. However, after the lesson with the intervention, they seem to have gained deeper conceptual understanding into the subject matter and hence, came to appreciate the essence of the negative sign associated with the mathematical expression for *Hooke's law*. This suggests that their learning of the subject matter was enhanced with respect to the DOS lesson.

#### **4.2.3.2.2. Students' perceived positive experiences with the PhET simulation-based intervention**

The results of the study also showed that students' enhanced learning of the physics concepts can be explained from the perspective of their perceived positive experiences with the PhET simulations-based intervention. In the second phase (i.e., Phase 2) of the

present study, an aspect of Student peers' questionnaire consisting of 14 items on opinions of the PhET simulation-based lessons was administered immediately after implementation of the two lessons by DTA2 and DTB2 on the DOS and FF lessons respectively. Possible answers to an item were scored on a five-point Likert scale (1 = strongly disagree, 2 = agree, 3=not sure, 4 = agree and 5 = strongly agree). A mean score of 3 and above indicated a positive favourable opinion while a mean score below 3 indicated a negative opinion of the Student peers' response. The items were pre-determined and grouped into 3 sub-scales about the Student peers' experiences in relation to their understanding of the PhET simulations-supported lessons. The sub-scales were: 1) Interest—this was aimed at finding out if the lessons engaged the learners' attention; 2) Comprehension— this was used to determine how clear and understanding the lessons were; and 3) Presentation—this was used to determine whether the content was well explained during the delivery of the PhET simulations-based lessons. Table 4.11 provides an overview of the Student peers' score on the 3 sub-scales after the lessons. The results indicate that the Student peers found the lessons very interesting and well understood. In addition, they perceived the presentation of the lessons to be attention grabbing; which promoted class participation. The overall means of the various aspects of the lessons reported by the Student peers were very high; Interest (Mean = 4.54, SD = 0.288), followed by Comprehension (Mean = 4.12, SD = 0.490), and then Presentation (Mean = 4.08, SD = 0.493). The differences reported between the two lessons for the sub-scales were quite close although sub-scales for lesson on *Deformation of Solids* were relatively lower in general. In particular, the difference in the Presentation sub-scale seemed to be more pronounced. The demonstrative form of inquiry adopted by DTA2 for the delivery of the lesson on *Deformation of Solids* might have contributed to this.

*Table 4.11: Student peers' score on the three sub-scales of the lessons*

<b>Subscale</b>	<b>Deformation of Solids DTA2 (N=9)</b>		<b>Frictional Force DTB2 (N=9)</b>		<b>Overall (N=18)</b>	
	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>	<b>Mean</b>	<b>SD</b>
Interest	4.50	0.280	4.58	0.306	4.54	0.288
Comprehension	4.06	0.507	4.20	0.491	4.12	0.490
Presentation	3.81	0.512	4.36	0.283	4.08	0.493

The results presented pertaining to the second part of RQ3 therefore suggest that the students (i.e., the Student peers in this study) enhanced their learning of physics concepts because of their improved students learning outcomes and positive experiences with the PHET simulation-based intervention.

### **4.3. Summary of the chapter**

In this chapter, results of the study were presented using both quantitative and qualitative evidence in addressing the three research questions that were considered for the purpose of tracking and understanding the development of pre-service teachers' competencies for integrating ICT (PhET simulation) in the teaching of high school physics in an interactive manner. The results have shown that the exemplary ICT intervention designed for the study promotes interactive teaching with its inherent features and thus, signifies the kind of ICT intervention that fit the realities in the senior high school physics classroom in Ghana. The study has also revealed that the pre-service teachers gained knowledge and skills in developing their own ICT-based interventions and that the ICT-based intervention developed in the study was found to be effective in improving the pre-service teachers' teaching practices and enhancing students' learning of concepts in physics. Furthermore, the results have shown that the pre-service teachers improved their teaching with ICT which was evident in their developed TPACK, improved content knowledge and developed competencies in the exploration of the PhET simulation environments.

The study has also revealed that the Student peers' learning of concepts in physics enhanced with ICT as their learning outcomes were found to have improved. That notwithstanding, the results have shown that enhancements in their learning were also evident in their positive experiences with the PhET simulations.

In the next chapter, I present a discussion on the findings of the study based on the literature reviewed in chapter two. Reflections and conclusions based on findings, implications and recommendations for practice, policy and future research are also provided in chapter five.

## **5. CHAPTER FIVE: DISCUSSION OF FINDINGS AND CONCLUSIONS**

### **5.0. Introduction**

This chapter is designed to discuss the findings of the study, provide conclusions, recommendations, and directions for further studies based on findings. In light of this, the results for each research question are discussed using the literature reviewed in chapter two as a lens and also, elucidated from the perspective of the theoretical underpinnings of the study as a way of ascertaining the significance of the findings. In addition, this chapter presents a reflective account on the Design-Based Research approach used in conducting the current study to substantiate the final design guidelines formulated as well as the key findings of the study. The chapter ends with concluding remarks to highlight what I have learnt from the study.

### **5.1. Summary of the study**

This research sought to track and understand the process of development of pre-service teachers' competencies for integrating ICT in the teaching and learning of high school physics in Ghana using PhET simulations as the interactive ICT tool. This was driven by the need to explore and design more effective and appropriate means of integrating ICT in the teaching of high school physics in order to improve teaching and enhance students' learning. To achieve the main goal, the study was guided by three objectives; to: 1) determine the features of an intervention that best fit the realities in the SHSs that can prepare pre-service teachers to effectively design and implement ICT using simulations as an interactive tool in teaching physics for the enhancement of students learning outcomes; 2) produce an effective ICT intervention for interactive teaching of physics and also for enhancing students' understanding of various concepts of physics in Ghana; and 3) provide an explanation and/or account of how and why improvements in teaching using ICTs and enhanced students' learning of physics concepts through the implementation process occurred. The research questions proposed to address these objectives were: RQ1, "What ICT intervention can be designed to fit the realities in the SHS classroom in a manner that makes the teaching of physics interactive?"; RQ2, "How effective is the ICT

intervention in improving teaching and enhancing students' learning of concepts in physics?"; and RQ3, "How can the improvements in teaching using ICTs and enhanced students' learning of physics concepts be understood and/or explained?" respectively. Thus, with the help of these three sub research questions, the study sought to answer the overall research question: "How can the process of development of pre-service teachers' competencies for integrating ICT in the teaching and learning of high school physics in Ghana be understood using simulations as an interactive tool".

Three theories constituted the conceptual framework for the study, namely: Constructivism, Technological pedagogical content knowledge (TPACK) (Mishra & Koehler, 2006), and the five dimensions for meaningful learning with ICT (5DML-ICT) (Howland et al., 2012 as adapted by Koh (2013)). Constructivism was used as the overarching theory for exploring pre-service teachers' experience in developing ICT-based activities and implementing it in a constructivist manner and also, for underpinning the idea of interactivity in the physics classroom. The TPACK framework was employed to unpack the kind of ICT-oriented knowledge that teachers need to drive interactive prospects with ICT (simulations). The 5DML-ICT framework as adapted by Koh (2013) was used as a lens to characterise and define interactive teaching and learning of physics with ICT (simulations). To adequately answer the research questions that guided the study, a Design-Based Research approach was adopted with an explanatory case study design using qualitative as well as quantitative evidence. Thus, data for the study were collected using semi-structured interviews, observations, focus group discussions, pre- and post-tests, questionnaires and the collection of the lesson artefacts designed. Multiple data sources were used for the analysis on the basis that a combination of these data sources through triangulation was useful for providing some level of flexibility in arriving at substantive explanations (Yin, 2003) in addressing the research questions. In particular, the quantitative data was analysed by use of descriptive statistics (i.e., mean and standard deviation) while for the qualitative, transcribed interviews and focus group discussions data were analysed by identifying themes as well as patterns. Document analysis was also employed to analyse and give meanings to the word-based data gathered from the pre-service teachers' simulation-supported lesson artefacts (i.e., Activity sheets, lesson plans and presentation slides).

## **5.2. Discussion of key findings**

The key findings of the study as emerged in chapter four of this thesis were based on the three sub research questions. Thus, this section discusses the key findings in accordance with the research questions so as to be able to answer the overall research question.

### **5.2.1. RQ1: What ICT intervention can be designed to fit the realities in the SHS classroom in a manner that makes the teaching of physics interactive in Ghana?**

Research question one was aimed at determining the features of an intervention that best fit the realities in the Ghanaian SHS classroom. Guided by the initial design guidelines which were formulated based on the literature reviewed (Agyei, 2012; Howland et al., 2012; Jonassen et al., 2008; Majumdar, 1997; Mishra & Koehler, 2006; Rehn et al., 2013; Wieman et al., 2007; Voogt & McKenney, 2016; Vygotsky, 1978; Wieman & Perkins, 2005), components of the exemplary PhET simulations-supported intervention such as: a) PhET simulation environment (see section 4.2.1.1., chapter 4); b) Interactive learning objectives (ILOs) (see section 4.2.1.2., chapter 4); c) Technological pedagogical content knowledge and the five dimensions for meaningful learning with ICT (TPACK-5DML) element (see section 4.2.1.3., chapter 4); d) Activity sheet element (see section 4.2.1.4., chapter 4); and e) Collaborative learning approach feature (see section 4.2.1.5., chapter 4) emerged as the features of the intervention that best fit the realities of the Ghanaian SHS physics classroom. These features informed the design and development of the two exemplary interventions (APPENDIX D: D1 and D2) used in this study. By these features, the exemplary ICT interventions seem to situate the teaching of high physics with PhET simulations in a learner-centred constructivist teaching and learning atmosphere by providing simulations-based avenues (e.g., Figure 4.1 and Figure 4.2, chapter 4) and structures through lesson activities (e.g., Excerpts 4.5 and 4.6, chapter 4) in order for learning to occur meaningfully.

In the subsequent paragraphs, each of the inherent features as identified in the exemplary intervention are discussed.

The affordances of both the *WS* (see Figure 4.1, chapter 4) and *GO* (see Figure 4.2, chapter 4) PhET simulations as highlighted in section 4.2.1.1. (chapter 4) seem to establish PhET simulations as an interactive ICT resource for supporting interactive teaching for meaningful learning in a learner-centred and interactive environment. Hence, the PhETs could be considered as one of the essential features of the ICT intervention that fits the Ghanaian SHS classroom. Guided by Rehn et al.'s (2013) definition of targeted simulations, the interactive nature of PhETs as observed in the study made PhET simulations perhaps, the most appropriate ICT tool to best cover specific topics in physics as well as support interactive teaching and learning of high school physics for meaningful learning outcomes (Wieman & Perkins, 2005). Furthermore, the interactive interfaces of both the *WS* and *GO* PhETs as highlighted in section 4.2.1.1. (chapter 4) apparently, project the PhETs to possess the needed potentials for stimulating students' interest in physics as a subject and also, providing an authentic platform for student to think critically as well as gain in-depth understanding of abstract concepts in physics (Wieman et al., 2007). These ideas as situated in literature were found to be instrumental to the design and development of the exemplary intervention. This is because, they served as essential building blocks for knowledge construction and also, a motivation for learning the subject matter through demonstrative, exploratory as well as discovery forms of inquiry.

The ILOs feature in the intervention (as elaborated in section 4.2.1.2., Chapter 4) was founded on Majumdar's (1997:2) assertion that with constructivism, teachers cease to be "transmitters of knowledge to guides". Seemingly, the inclusion of the ILOs feature in support of the specific learning objectives was necessary for ensuring that instructional and learning processes take place in an atmosphere that is highly driven by interactions, reflections, and learners' personal experiences with the aid of the ICT tool and not in a teacher-centred setting. Hence, the ILOs feature of the exemplary intervention appears to bring to bear the concept of interactivity in the physics classroom.

Guided by Mishra and Koehler's (2006) TPACK framework and Howland et al.'s (2012) concept of "Five dimensions for meaningful learning with ICT", the TPACK-5DML element (as elaborated in section 4.2.1.3., chapter 4) was initiated for the sole purpose of bringing into practice how interactive teaching with ICT is realised and driven by teachers' specific ICT-oriented knowledge (TPACK) for the creation of a constructivist classroom for meaningful learning outcomes. This element (see Figure 4.3, chapter 4) seems to inspire Voogt and McKenney's (2016) proposition that TPACK is the conceptual base to consider for studying the kind of knowledge teachers require to use technology to teach.

The activity sheet element as reported in section 4.2.1.4. (chapter 4) was informed by Agyei (2012:13) assertion that "students must be active during learning" in order to effectively project the constructivists' ideas of learning. Thus, the activity sheet element as incorporated in the intervention, perhaps, reflects various ways in which interactivity as defined by use of the *Active, Constructive, Intentional, Authentic, and Cooperative* dimensions (Howland et al., 2012) could be realised in order to promote the learner to take full responsibility of the learning process as well as stimulate and also, sustain their interest throughout the instructional process.

Vygotsky's (1978) idea of social constructivism adds a collaborative dimension to the instructional process. As emphasised in section 4.1.2.5. (chapter 4), the collaborative learning approach feature was intended to facilitate the creation of a friendly environment for learners to learn from each other, appreciate different ways of seeing the world and also, foster learners' understanding of concepts that under normal circumstances, they would not understand on their own. In this regard, the collaborative approach feature of the exemplary intervention seems to project Vygotsky's idea and hence, appears to establish the benefits of social interactions in the classroom in light of Jonassen et al.'s (2008) description of the cooperative attribute of meaningful learning as collaboration propelled by conversations.

By drawing on literature, each feature of the exemplary ICT intervention as discussed herein seemed carefully chosen and incorporated to uniquely promote interactive teaching as shown in chapter 4 of this thesis. These inherent features seemingly position the exemplary intervention as one of the important means by which pre-service teachers could be inspired to gain deeper understanding into ICT-based innovations for the development of competencies for integrating ICT into their teaching practices in an interactive manner. While it can be said that perhaps, the exemplary intervention possesses the appropriate features that are sensitive to the needs of the Ghanaian senior high school classroom, the same statement may not be true for other countries in that these features as identified in this study may not apply to their classroom contexts; which could differ. Nevertheless, it is encouraging to mention that the exemplary intervention could be adapted to incorporate features that meet the specific needs of other contexts especially, in Sub-Saharan Africa.

### **5.2.2. RQ2: How effective is the ICT intervention in improving teaching and enhancing students' learning of concepts in physics?**

The effectiveness (also referred to as “interactivity” in this study) of the ICT intervention was determined by measuring the extent to which the five dimensions for meaningful learning with ICT (Howland et al., 2012): *Active, Constructive, Authentic, Intentional, Cooperative* were realised in the design and implementation of the PhET simulations-based intervention.

Findings in this regard emerged at two levels (as reported under sections 4.2.2.1 and 4.2.2.2 of chapter 4) under the themes: 1) Pre-service teachers' reported lesson interactiveness and 2) Student peers' perceptions about the interactiveness of the PhET simulations-based lessons. Responses from the focus group discussions, activity sheets, lesson plan documents, observation data and the five-dimension survey were employed in order to examine the effectiveness of the ICT interventions from the perspective of the pre-service teachers while responses from focus group interviews with Student peers and the Student peers' survey (Table 4.6) were used as evidence for determining the

effectiveness of the interventions from the perspective of the Student peers. In general, findings from both perspectives showed that the ICT (simulation)-based intervention designed and developed in the study was effective in improving teaching and enhancing students' learning of concepts in physics because, it promoted interactive teaching and meaningful learning in a constructivist instructional atmosphere and consequently, yielded positive learning outcomes. From the perspective of the pre-service teachers, both qualitative and quantitative results showed that all the four ICT-based lessons were interactive. The qualitative results (e.g., Table 4.2, Table 4.3, Table 4.4, Figure 4.6, and Figure 4.7) showed that the Design Teams (pre-service teachers) used the PhET simulations to: 1) engage their learners in learning the subject matter (*Active*); 2) stimulate their learners to go beyond reflecting on the subject matter to forming and expressing their own personal meaning of the subject matter (*Constructive*); 3) enforce ownership on the part of learners through authentic tasks with a focus on creating learning platforms for linking 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 in order to promote team work abilities of the learners (*Cooperative*). These findings were confirmed by the quantitative results which reported favourable responses for all the five dimensions with respect to each of the ICT-based lessons developed (see Table 4.5, chapter 4) and also, recorded overall means of values: 4.01, 4.17, 4.04, 4.25, 4.08 for the *Active*, *Constructive*, *Authentic*, *Cooperative* and *Intentional* dimensions respectively (see Figure 4.8, chapter 4). These results as reported by the pre-service teachers were also confirmed by the Student peers. This was evident in their responses during the focus group interview. The results showed that the Student peers perceived the lessons they witnessed to be interactive in that all the five dimensions could be identified in their comments (see section 4.2.2.2., chapter 4). Analyses of the Student peers' survey (Table 4.6, chapter 4) also reiterated that the ICT-based lessons they observed were interactive as it promoted meaningful learning.

Thus, findings from both pre-service teachers and Students peers that were involved in the study herein emphasise the fact that the PhETs employed in this study for the implementation of the ICT-based interventions tended to promote the teaching of physics to be effective in a constructive way and consequently, yielded positive learning outcomes. This aligns with Brush and Saye's (2000) finding that when ICT is used with a constructivist teaching approach, positive learning outcomes are ensured. In addition, the finding herein is consistent with Bell and Smetana's (2008) observation that the effectiveness of simulations when used for instructional purposes is highly dependent on the way and manner in which it is used in the classroom—placing emphasis on the pedagogical approach to be adopted with simulation for lesson delivery. This also reflects 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. In the current study, evidence in this regard revealed that meaningful learning was ensured with keen interest in providing learners with an interactive platform by use of the PhETs for facilitating personal experience, making meaning and in-depth understanding of the concepts in physics which afforded students' conceptual change. Hence, it appears that the PhETs' use in this study was key to ascertaining interactivity with the ICT (simulations)-supported intervention owing to its vehicular and rich catalytic characteristics as an interactive tool (Howland et al., 2012; Volman, 2005). This seems to have greatly informed the teaching strategies that were adopted by the Design Teams for the delivery of the PhET simulation-based interventions in a constructivist atmosphere. While this may be true for the exploratory self-directed form of inquiry as used in this study, the same may not apply wholly for the demonstrative form of inquiry. The results (see section 4.2.2.1., chapter 4) showed that the demonstrative approach used in the delivery of the PSSPL \_3 lesson (in which only the teacher had access to the technology resource) was relatively less learner-centred (though interactive in nature) compared to the lesson that adapted the exploratory approach. Perhaps this was because the Student peers who witnessed the PSSPL \_3 lesson did not get the opportunity to explore the simulations environment by themselves since the classroom situation that was adopted for the design and implementation of the lesson was such that only the teacher had access to the computer (or simulation environment). Consequently, it appears that the

demonstrative form of inquiry propelled the lesson to be skewed towards the teacher-centred approach; depriving learners of access and personal experiences with the selected PhET environment for that particular instructional session with the PSSPL \_3 intervention. This helps to substantiate the results that the exploratory self-directed inquiry adopted by the pre-service teachers in the development and implementation of their respective interventions provided an interactive avenue for promoting more learner-centredness compared to the demonstrative form of inquiry. My findings in this regard speak to what Bransford, Brown and Cocking (2000) implied when they hinted that the effect of ICT on the teaching of physics for positive results was highly dependent on how teachers used ICT in their classrooms.

The findings (see sections 4.2.2.1 and 4.2.2.2 of chapter 4) as reported by both the pre-service teachers and the Student peers that the PhET simulation-supported intervention was effective also suggest that the five dimensions for meaningful learning were not realised in isolation for interactivity to be achieved, rather it was more of their combined effect in each of the developed and enacted PhET simulation-based lessons that seemed to have provoked the ICT-based interventions in this study to be effective. This finding aligns with Jonassen et al.'s (2006:3) assertion that "learning and instructional activities should engage and support combinations of active, constructive, intentional, authentic, and cooperative learning because they are synergetic". The authors' assertion echoes the fact that the five dimensions for meaningful learning do not exist in isolation and thus, seems to project the synergetic (combined) effect of the five dimensions as an essential and necessary ingredient for effective instructional process.

Although the results seem to suggest that a combination of all the five dimensions was key to attaining interactivity with each of the PhET simulations-based physics lessons, their unique contributions as perceived by both the pre-service teachers and Student peers seem to differ from one dimension to the other. This was particularly so for the *Cooperative* which was most projected (see Table 4.5 and Figure 4.9, chapter 4). Apparently, the pre-service teachers 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 intervention as a sustaining element (i.e., the necessary condition; see Figure 4.8) for ensuring that lesson activities were executed in diverse ways to promote interactivity with the interventions irrespective of which dimension(s) the lesson activities were specifically purposed to project. This seems to hint that the *Cooperative* dimension goes beyond providing platforms for divergent knowledge expressions as suggested by Koh (2013) to inherently sustain the other four dimensions in order to facilitate the creation of an interactive teaching and learner-centred environment for meaningful learning to be attained with ICT, especially with the PhETs.

Another dimension that was noticeable was the *Active* (see Figure 4.9, chapter 4). Unlike the *Cooperative* dimension, the *Active* dimension was perceived as the least among all the other dimensions in realising interactivity. It is not clear what might have accounted for the reported least projection of the *Active* dimension. However, it appears that the pre-service teachers might have misconstrued the *Active* dimension to imply *Constructive*. Perhaps, because in their quest to engage learners in learning the subject matter with the PhETs in their design of the lesson activities, the activities tended to provoke the learners to express their ideas and make meaning of the subject matter beyond what had been presented to them as the results from Table 4.3 suggest. Seemingly, this does not align with Koh's (2013:887) assertion that "being active does not necessarily imply being constructive". By this assertion, Koh cautioned that this was one of the issues to be considered and resolved in any attempt to operationalise each of the five dimensions for meaningful learning in that there is a need to give attention to how ICT defines the *Constructive* dimension by involving active learning. This seems to be the challenge that the pre-service teachers of the study might have faced as they might have had difficulties in clearly distinguishing between the *Active* and the *Constructive* dimensions of interactivity.

Another challenge the pre-service teachers faced was their inability to implement their ICT-based lessons effectively within the stipulated time. The qualitative results (as highlighted in section 4.2.2.4. of chapter four) showed that most of pre-service teachers could not deliver their lessons within the allocated 80 minutes they had indicated in their

lesson plans as per the stipulations of the Ghanaian physics curriculum for SHS document. This seems to have limited the learners in their explorations with the simulation environment in learning the subject matter. The issue of limited time as found in this study, confirms Güzel (2011) finding that time is an impediment to the success of computer supported physics classes. It appears that limited time affected two areas of the implementation process of the ICT-supported physics lessons in this study: 1) the allocated lesson delivery duration and 2) learner-ICT (simulations) interaction. These two areas seem crucial as they constitute the core of the whole instructional discourse with ICT (PhET simulations) where interactivity is of utmost interest. Thus, time posing as a hindrance in these directions could have greatly influenced the way learning occurred with the intervention.

Weaknesses in the PhET simulations were also perceived to have limited the effectiveness of the ICT interventions developed. This seemed more pronounced with the BL simulation environment as highlighted in section 4.2.2.4. of chapter four. The results showed that the pre-service teachers could not control or resolve these weaknesses (e.g., unclear markings below 5 degrees on the virtual protractor in the BL simulations and the appearance of a thick incident or refracted ray; see Figure 4.10) as they seemed more of “software developer-related weaknesses”. Apparently, these weaknesses made it difficult for the pre-service teachers to take accurate readings with the virtual protractor and consequently, seemed to have affected the learning outcomes anticipated with the activities developed based on the virtual protractor as well as the ray feature of the BL simulations. This aligns with Groff and Mouza’s (2008:34) assertion that “... by its very nature, technology brings its own challenges and therefore, creates its own barriers to success in the classroom”. The results therefore suggest that the inherent weaknesses in the PhETs’ environment impeded its own use in the instructional process.

In spite of the weakness/difficulties discussed, the results showed a number of reasons why the ICT intervention appeared effective in improving teaching and enhancing students’ learning of concepts in physics. The following sections discuss the results that emerged in this respect.

Firstly, the results (e.g., focus group interview, observation data, lesson plan document; see section 4.2.2.2., chapter 4) showed that the facilitating roles as adopted by the pre-service teachers during their enactment of the simulations-based lessons may be one of the reasons that accounted for the interactivity (effectiveness) achieved with ICT interventions developed in this study. In particular, the results (e.g., Excerpt 4.15, chapter 4) showed that facilitating modes such as the provision of summaries, engagement of learners' prior knowledge, supervision of learners' activities and the creation of platforms for discussion as adopted by the pre-service teachers helped to promote interactivity. It appears that these modes of facilitation represent the kind of support structures the pre-service teachers employed in order to ensure that their anticipated learning outcomes were effectively realised with the ICT tool. This finding supports the results of Bell and Smetana (2008) which showed that the effectiveness of simulations when used for instructional purposes is highly dependent on the support structures put in place. Interactivity as attained through the use of the facilitating modes (see Excerpt 4.15, chapter 4) also seems to suggest that the PhET simulations with its remarkable affordances stimulated the pre-service teachers to shift their roles in the physics classroom from that of a "transmitter of knowledge to guide & facilitator of knowledge" (Majumdar's, 1997:2) and hence, supports the finding that the ICT-based intervention was effective in improving teaching.

Secondly, the results showed that the minimal level of guidance provided by the Design Teams in their respective activity sheets apparently, was another reason for the interactivity achieved with ICT interventions developed in this study. It appears that the pre-service teachers' adoption of minimal level of guidance was influenced mainly by the interactive interface of the various PhET simulations used in the study (see comments in section 4.2.2.3., chapter 4). This seems to align with Wieman, et al.'s (2010:225) assertion that computer simulations "... rely on the timely guidance of a teacher". However, the results seem not to entirely support Adams et al.'s (2008:1) finding about "What level(s) of guidance are needed with the PhETs for effective teaching?" which seems to suggest that "minimal guidance" implied a "Type B" level of guidance; a type of

guidance that is conditioned with driving questions. This is because the results (e.g., Excerpts 4.15b, 4.15c and 4.15d under section 4.2.2.3., chapter 4) seem to champion minimal guidance with the PhETs to extensively involve not only driving questions (referred to as content-driving follow-up questions in this context), but also the use of instructions, snapshots from the simulation environment, and tables in the design of the activity sheets with emphasis on stimulating learners to develop mental bases that are inspired by their own thinking, questioning and personal experiences with the PhETs.

### **5.2.3. RQ3: How can the improvements in teaching using ICTs and enhanced students' learning of physics concepts be understood and/or explained?**

The discussion pertaining to research question three (RQ3) are presented in two parts as was done in chapter four with the results. Thus, in next two subsections (i.e., 5.3.1 and 5.3.2), findings in relation to RQ3 are discussed in order to explain how: 1) teaching improved using the PhETs and 2) students' learning of physics concepts were enhanced with the PhETs respectively.

#### **5.2.3.1. Improvement in teaching using ICT (PhET simulations)**

Improvement in teaching using ICT (PhETs) was explained using both quantitative and qualitative evidence (i.e., TPACK self-assessment questionnaire, lesson plan documents, observation, interview, and focus group discussions) collected during the implementation and evaluation stages of the study. These were designed to track how the pre-service teachers constructed their knowledge while developing and integrating ICT-based lessons. The results from both quantitative and qualitative evidence showed that teaching improved with ICT (PhETs) because of the pre-service teachers' enhanced TPACK, improved content knowledge (CK) and better competencies for the exploration of the PhET simulation environments (i.e., developed technology knowledge, TK) (see sections 4.2.3.1.1., 4.2.3.1.2., and 4.2.3.1.3. of chapter 4). These characteristics of the pre-service teachers as found herein seem to depict the key ingredients for effectively enabling a shift from the teacher-centred teaching method to a learner-centred teaching method (Voogt,

2003) in the physics classroom where technology is involved. This seems to hint that with these acquired competencies in ICT, pre-service teachers' teaching practices may begin to improve. Findings in this regard seem to fill in a gap in the literature by defining how the shift in paradigm as far as effective teaching strategies with ICT are concerned could be made a reality. Most scholars (e.g., Scheurs & Dumbraveanu, 2014; Voogt, 2003) only seem to make emphasis on the need for the shift in the teaching approach, but have not paid adequate attention to how the proposed shift could be effectively realised. In the subsequent sections, I discuss how the findings as mentioned herein begin to explain the shift suggested in literature.

#### **5.2.3.1.1. Pre-service teachers' developed TPACK**

The results from the lesson plan documents (e.g., Excerpt 4.18 and Excerpt 4.19), interview and focus group interview data (see section 4.2.3.1.1.) provided evidence that the development of TPACK by the pre-service teachers appears to facilitate a shift in paradigm. This is seen in the way the Design Teams practically combined their technology knowledge, pedagogy knowledge, and content knowledge in the design and enactment of the intervention. The lesson plan documents for example showed that the pre-service teachers did not only consider implementing TPACK as a unique body of knowledge, but also sought to bring to light the simple combination of the three knowledge bases during their teaching with the intervention (see Excerpt 4.18 and 4.19). This seems to suggest that both the transformative as well as the integrative nature of the TPACK framework as discussed in literature (Chai et al., 2010; Harris et al., 2009) are necessary ingredients for realising a positive shift in the teaching paradigm. The finding here illustrates that both views about the nature of the TPACK model are crucial for providing the basis for understanding how teaching improved based on the pre-service teachers' developed TPACK in the context of the study which apparently, led to a positive change in the prospective teachers' ways of teaching physics. However, the road to this positive change in the pre-service teachers' developed TPACK was not without some difficulties. As observed in the interview data (see section 4.2.3.1., chapter 4), the results indicated that the pre-service teachers had difficulties in establishing relationships between the physics

content, teaching strategies, and the affordances they had discovered with the selected simulation environment in the initial stages of the design and development of the simulations-supported lessons. Being novices to the PhET simulation environment and rooted in their existing pedagogical content knowledge (which reported a mean value of 3.69 at the beginning of the PDA) as depicted in Figure 4.11, the pre-service teachers had not yet gained the knowledge and skills required for exploring and understanding the affordance of PhET simulations to incorporate its use in the teaching and learning of the subject matter. This is consistent with Hutchison and Reinking's (2011) observation that when teachers lack the required ICT-oriented knowledge, they seem to have difficulties in building on their existing pedagogical content knowledge. Another reason that could explain their difficulty in this regard was perhaps, the fact that the pre-service teachers had not yet come to terms with how their teaching with the PhET as defined by the interconnections that exist among the three core knowledge domains of the TPACK framework could be situated in unique contexts in order to reflect the realities in the Ghanaian physics classroom. This seems to echo the importance of "context" in practicalising the TPACK model as emphasised by the authors of the TPACK model (Mishra & Koehler, 2006). Another challenge observed in the process of development of the pre-service teachers' TPACK was perhaps, the difficulty they encountered in shifting from the traditional approach of teaching to a learner-centred way of teaching physics. The results seem to be an indication that the pre-service teachers at the beginning of the PDA were deeply rooted in the teacher-dominated strategies for teaching physics to the extent that they may have perceived pedagogy to mean a teaching approach that is purely teacher-centred irrespective of the instructional tool adopted. This is consistent with Agyei's (2012) observation that the teacher-centred approach is the main teaching approach being adopted to train the prospective teachers in Ghana. Based on this difficulty at the beginning of the PDA, the overall low PK score (3.55) as reported by the pre-service teachers at the end of the PDA (see Figure 4.1) could be interpreted to mean that the pre-service teachers no longer perceived pedagogy to mean teacher-centred approach after the design and implementation of the ICT-based intervention. This explains why there was decrease in their PK (see Figure 4.1) after the design of the interventions and also, suggests that the pre-service teachers had come to develop

competencies in ICT-related pedagogies that were constructive in nature with the help of the PhETs at the end of the PDA.

#### **5.2.3.1.2. Pre-service teachers' improved content knowledge**

The finding that teaching improved with the PhET-based intervention because the pre-service teachers improved in their content knowledge (see section 4.2.3.1.2., chapter 4) also seems to have facilitated a positive shift in the pre-service teachers' teaching paradigm. The results from the interview data, presentation slides and their presentations (section 4.2.3.1.2., chapter 4) showed that the participating pre-service teachers shifted from teaching physics in abstraction to embrace a teaching approach that was founded on better understanding of the subject matter. This was evident in their enhanced understanding of the subject matter which seemed to have been driven by the affordances they had discovered in relation to the PhET simulation environment they worked with—emphasising the important role simulations play in promoting content development. This finding provides support to the view that an understanding of affordances of technology facilitates enhanced content knowledge. This concurs with Bell and Smetana's (2008) findings about the use of computer simulation in science classrooms. According to the authors, simulations are essential for the development of content knowledge and as can be inferred from the results herein, the PhETs provided a learning platform for the pre-service teachers in the context of this study to fill in the gaps in their knowledge about the subject matter. This was useful for improving their teaching practices. Apparently, their efforts as teachers were much improved with the PhETs, and this further supports Wieman et al.'s (2010) assertion that simulations have the potential to enhance the efforts of a teacher. In this case, the pre-service teachers were able to better explain various concepts in physics that otherwise looked very abstract (Donnelly et al., 2011); an indication that their content knowledge had improved somehow.

### **5.2.3.1.3. Pre-service teachers' developed competencies in the exploration of the PhET simulation environments**

Improvement in teaching with the PhETs was also as a result of the developed competencies of the pre-service teachers in the exploration of the PhET simulation environments (section 4.2.3.1.3., chapter 4). The paradigm shift in this regard can be explained as shown by the results from the interviews and focus group discussions (see section 4.2.3.1.3., chapter 4) to stem from the adoption of three strategies: 1) consistent engagement with various PhET simulation environments; 2) in-depth interaction with the content-driven interactive features of the PhET simulation environments; and 3) comprehensive preparations made prior to the lesson enactment with the PhET-based lessons by the pre-service teachers. These strategies facilitated the development of the participants' competencies in the exploration of the PhETs (i.e., improved their technology knowledge) which was essential for enabling the improvements observed in the pre-service teachers' way of teaching of physics. This confirms Webb and Cox's (2004) assertion that when ICT is used in the classroom, it has a lot of implications for teachers. In this context, the pre-service teachers had to put in much effort in using the aforementioned strategies as the necessary learning medium through which they used the PhETs in teaching physics effectively. Consequently, the results suggest that by adopting these strategies, the pre-service teachers were able to identify the weaknesses in the various PhET environments they explored; discover as well as gain deeper understanding into the affordances of the PhETs; and identify appropriate instructional approaches that facilitated student's conceptual understanding of the various concepts selected for the design of their respective interventions. With these outcomes, it appears that the pre-service teachers' adoption of the three strategies for the exploration of the sims was successful in creating an interactive learning environment through the use of the ICT tool for promoting meaningful learning. Their roles in the classroom as teachers seem to have changed as they developed their competencies in the exploration of the PhET simulations as informed by the three strategies they adopted. One interpretation is that their exploits with the PhETs shaped their teaching practices by helping them to focus on the learning needs of their learners for the development of an interactive instructional

environment that is driven by creativity on the part of the teacher, instead of assuming unwarranted control over the classroom discourse as a teacher. In addition, their exploration of the PhETs seems to have shifted their attention from learning to use the PhET simulations as an ICT tool to integrating it into their teaching practices in a manner that champions meaningful learning. These findings align with Majumdar's (1997:2) assertion that the teacher's role with ICT in the picture, changes from "controller of learning to creator of learning environment" as well as "learning to use ICT to using ICT to enhance learning". Thus, the pre-service teachers' shift in paradigm that surfaced in relation to their developed competencies in the exploration of the PhETs; this partly explains why teaching may have improved.

In spite of the fact that the development of competencies in the exploration of the PhETs seems to have facilitated a shift in paradigm with respect to their teaching practices, it is important to mention that some pre-service teachers in the study initially encountered difficulties in exploring their first PhET simulation environment due to insufficient content knowledge. As a result, they seem to have struggled to engage their prior knowledge of the subject matter in order to discover the affordances of the simulation environment they were tasked to explore prior to the intervention (see section 4.2.3.1.3., chapter 4). This suggests that these pre-service teachers might have initially over-rated themselves as having sufficient CK (3.80 for DTB11 and 3.60 for DTB12) as observed in Table 4.8 with the results from the TPACK pre-survey when in reality, their content knowledge was insufficient. Thus, the finding emphasises that their lack of sufficient content knowledge at the beginning of the PDA was a hindrance to their discovery of the affordances of the PhETs simulations. This provides support to the assertion that content is a necessary ingredient for effective teaching with technology (Mishra & Koehler, 2006).

#### **5.2.3.2. Enhanced students' learning with ICT (PhET simulations)**

Enhanced students' learning of physics concepts with the PhETs was explained based on the Student peers' improved learning outcomes (see section 4.2.3.2.1., chapter 4) and their perceived positive experiences with the PhET simulation-based intervention (see

section 4.2.3.2.2., chapter 4). Results in this regard were based on the two ICT-based interventions (namely, PSSPL\_3 and PSSPL\_4) that were witnessed by the Student peers (i.e., pre-service teachers who posed as senior high students during the enactment of the interventions).

The findings (e.g., Table 4.10, Excerpts 4.22a, 4.22b, 4.23a and 4.23b; section 4.2.3.2.1., chapter 4) on enhanced students' learning with the PhETs can be explained from the Student peers improved learning outcomes. The use of the PhETs in the teaching and learning process facilitated enhancements in the learners' understanding of concepts under the topics: *Frictional Force* and *Deformation of Solids*. Specifically, the PhETs helped to clear their misconceptions as well as enabled them to form their own personal meanings of the concepts. The finding herein seems to imply that the affordances of PhET simulations promoted students' conceptual change as well as conceptual development of the subject matter—an indication of the extent to which PhETs facilitated understanding of the concepts taught. This explanation is consistent with findings from previous studies (Barak & Dori, 2005; Dega et al., 2013; Jimoyiannis & Kosmis, 2001; Trundle & Bell, 2005). Specifically, findings in these studies situate computer simulations as a useful tool for the enhancement of students' conceptual understanding of concepts in physics.

The enhanced students' learning of physics concepts with the PhETs could also be explained based on the Student peers' perceived positive experiences with the PhET simulation-based intervention. In particular, the results (see Table 4.11) showed that the Student peers considered: a) the simulations-based lessons to be interesting, b) the physics concepts presented and discussed in the course of the lesson to be clear and well understood, and c) the lesson presentations with the PhETs to be attention-grabbing. These seem to suggest that the PhET simulation environments (entitled: *Hooke's Law* and *Force and Motion: Basics (Friction)*) selected for the design and development of the lessons on the topics: *Deformation of Solids* and *Frictional Force* respectively, shaped students' learning of the subject matter for the better by motivating their interest in the subject matter, facilitating their understanding of the concepts studied, and engaging their attention throughout the instructional discourse (Wieman et al., 2007).

### **5.3. Limitations of the study**

In this study, a case study strategy was employed using both quantitative (questionnaires, pre- and post-tests) and qualitative evidence (semi-structured interviews, focus group discussion and observation, researcher's logbook, lesson artefacts). Though each method adopted for data collection has its own inherent errors and limitations which cumulatively may affect few results and conclusions drawn, the different approaches were complementary when triangulated; thereby improving confidence in the findings.

The case study design allowed for only limited number of participants to be used in the current study. Thus, generalising the results to a larger population is not possible. The study however adopted an explanatory type of case study in order to make analytical generalisations that are important for the formulation of design guidelines. The iterative process as afforded by the DBR was upheld to ensure that explanations given in the study were "independent of any methodological biases" (Harder, 2012:3). Data collected from both quantitative and qualitative evidence were also triangulated to strengthen the veracity of any explanation given (Yin, 2003).

In this study, I assumed a dual role as the researcher and the facilitator during the initial training workshop. I observed the pre-service teachers during their enactment of the interventions they developed and I was also involved in the focus group discussion sessions as I needed to take notes as well as record the proceedings to that effect. Thus, the issue of researcher biases was inevitable. Reflexivity and the use of multiple sources of data therefore provided the basis for resolving this issue through triangulation.

The study was context-bound in that, pre-service teachers considered for the study were selected from only one higher education institution in Ghana (University of Cape Coast). This could limit transfer of the study to other higher education institutions. The pre-service teachers had physics as their major teaching subject. This placed a limitation on the extent to which data as well as outcomes of the study could be applied to other science subjects such as biology and chemistry and its application.

#### **5.4. Reflections on research approach**

The present section reflects on the research approach (i.e., design-based research, DBR) as adopted in the present study. The reflections take into consideration the design, development, and try-outs of the intervention in order to substantiate DBR as the possible approach for improving pre-service teachers' knowledge in developing ICT based physics lessons in an interactive way by use of simulations.

In this study, design-based research was considered as an appropriate research approach based on its iterative nature which allows for a systematic refinement of an intervention. This was deemed relevant for gaining valuable insights into how the pre-service teachers developed their knowledge and skills for integrating ICT into the teaching of physics using PhET simulations as the interactive tool. DBR was also useful for the formulation of design guidelines that inform theory in order to facilitate prospects in future development of pre-service teachers' competencies for ICT integration (Agyei, 2012). Each stage of the DBR approach as situated in the study facilitated the production of an effective ICT-based instructional intervention. This was key to providing a realistic solution to the non-interactive methods of instruction being adopted for the teaching of physics in Ghana. The design stage for example, provided the platform for the researcher to be innovative based on the literature reviewed. This was useful in identifying the initial design guidelines. The design stage also provided room for experts to ascertain the practicability as well as improve the validity of the exemplary intervention; hence, the design stage as incorporated in the study was crucial for the production of a quality intervention with features that best fit the Ghanaian classroom context.

The implementation and evaluation stage of the DBR approach formed the core of the research. Through the professional development arrangement organised at this stage, the hallmark of DBR (i.e., the iterative cycle) was emphasised. The iterative cycle of formative evaluation and redesign as done in the PDA provided an avenue for the researcher to describe the extent to which the designed intervention was delivered as intended. In this regard, the microteaching try-outs and the feedbacks given after each

try-out became central to ascertaining the effectiveness of the ICT (simulations)-based intervention.

The last stage of the DBR enabled reflection and documentation about the entire research process from the design to implementation of the intervention. This gave birth to the theory (i.e., the refined and final design guideline) formulated in this study for the design of an effective PhET simulations-supported physics lesson. Also, the last stage provided a thought-provoking atmosphere for gaining deeper insights into the developmental process of the pre-service teachers as they worked in Design Teams to integrate the PhETs into their teaching practices for meaningful learning outcomes. Thus, it is important to stress that the reflection and documentation stage provided the foundation for explaining how the improvements in the teaching of physics with ICT, as well as the enhancements in students' understanding of concepts of physics occur in an ICT implementation process. The in-depth explanations sought after at this stage of the DBR approach brought out the essence of the explanatory case study design adopted for the study. This enabled me to closely examine the data gathered in the course of the study within specific contexts "both at a surface and deep level" (Zainal, 2007:3). In this regard, it suffices to indicate that the DBR approach with the (explanatory) case study design formed the basis for situating the present study in a qualitative research. The refined and final design guidelines (i.e., theory) formulated on these grounds are presented under section 5.5.

### **5.5. Reflections on key findings and contribution to scholarship**

This section is intended to reflect on key findings and also highlight the study's contribution to knowledge based on the outcomes of the study. In particular, the reflections are done in relation to the following: design guidelines formulated for the study, the TPACK framework, the 5DML-ICT model, and the PhET simulations as an interactive ICT tool.

### **5.5.1. Design guidelines (final)**

One major outcome of this study is the formulation of design guidelines which is an important element in applying Design-Based Research in any study. Hence, based on the findings of the study, the following design guidelines are formulated to facilitate future endeavours of pre-service teachers in developing competencies in ICT integration for the teaching of high school physics:

- Exemplary intervention in the form of lesson artefacts are relevant curriculum materials for ICT integration in physics education. They provide practical and authentic samples for pre-service teachers to gain in-depth understanding of what an ICT-based innovation constitutes.

Although, exemplary interventions serve as important guides for pre-service teachers in their use of ICT, it is worth mentioning that there is a tendency for the pre-service teachers to replicate the exemplary material. This could prevent them from being creative in the design and development of their own ICT-supported lessons. Thus, careful measures should be taken to ensure that pre-service teachers have adequate understanding of the design process in light of theory.

- Adoption of an ICT tool that is readily available, user friendly, content-related, and sustainable in the context in which it is to be used is essential for the development of ICT-oriented competencies.
- Design Team approach is an important way to groom and support pre-service teachers' learning with ICT. By this approach, pre-service teachers are encouraged to collectively work with their peers. Consequently, the teaching practices and learning prospects of the pre-service teachers with ICT become situated in a social context. This facilitates their way of knowing about the technological tool in mastering the subject matter.
- Initial training workshop is an important means to equip teachers with ICT-oriented teaching and learning competencies that are not technocentric. This approach of professional development arrangement is theory-induced and content-focused.

Hence, it is considered essential for preparing pre-service teachers to effectively incorporate ICT into their teaching.

- A purposeful inquiry as defined in a self-directed exploratory or demonstrative form of inquiry is key to a successful implementation process with ICT. These forms of inquiry reflect the constructivist ideologies of a learner-centred way of teaching. It is important to mention that such forms of inquiry are sensitive to the context in which the instructional process is to occur.
- Adoption of facilitating modes such as provision of summaries, engagement of students' prior knowledge, supervision of students' activities, and the creation of platforms for discussions are key to effective implementation of an ICT innovation. These characterise the needed support structures with capacities that drive the instructional process with ICT. This is important; as when incorporated in the preparation arrangement for pre-service teachers in their uptake of ICT in the classroom, it will enhance their understanding of the various facilitating roles that a teacher can adopt for the creation of a constructivist teaching and learning environment where learner-centredness is most emphasised.
- Scaffolds and interactive technology experiences such as exploratory hand-on exercises with an ICT tool in relation to the subject matter, discussions pertaining to ICT-oriented teaching strategies, and teaching try-outs with peers should be incorporated in such teacher preparation programme which has the intent to develop pre-service teachers' knowledge and skills in ICT integration. These give pre-service teachers the opportunity to: 1) link their content knowledge to unfolding how the content is best represented based on the affordances of an ICT tool, and 2) learn from one another in order to identify effective ways to design and implement their ICT-based lesson artefacts; especially, the lesson plans and activity sheets. It is worth mentioning that this design guideline is key to tracking the development of pre-service teachers' ICT integration competencies as it lays the foundation for gaining valuable insights into how a shift in paradigm is realised with ICT during a professional development arrangement.

The following design guidelines are also formulated specifically to facilitate PhET simulations' use in the Ghanaian senior high school physics classroom:

- Sufficient content knowledge promotes effective teaching with PhET simulations. This is important for the discovery of the PhETs' affordances in relation to the subject matter.
- A strong relationship between the PhETs as a technological tool, the subject matter (physics), and strategies that are to be adopted with the PhETs should exist and also reflect in the lesson artefacts that constitute the PhET-based intervention. This is key to attaining a successful integration of PhET simulations into the teaching of physics as it serves as a lens for appreciating the extent to which a teachers' ICT-oriented knowledge (TPACK) and skills could be put into practice.
- Advance preparation is essential for interactive use of the PhETs in the physics classrooms. This affords the teacher, an authentic platform to critically think through: a) what physics topics to teach with the PhET simulations; b) what method to adopt to promote the constructivist way of teaching (i.e., learner-centred approach of teaching); c) the context or classroom situation to adopt for the lesson with the PhETs; and d) the affordances of the selected PhET simulation environment that will best guide a learner in the high school to develop his/her conceptual understanding of the subject matter as well as the type of simulation-based activities to develop in order to aid students to construct their own knowledge and promote their class participation. This allows the teacher to think about his learner at every stage of the instructional process with the PhETs, and also enables the teacher to identify probable difficulties that learners might encounter in their exploration of the PhETs in order to put in place measures to resolve them before the lesson, if possible.
- In-depth exploration of the PhETs is also crucial for effective integration of the PhETs into the instructional process as this guides the teacher to identify appropriate learning objectives and develop practical, interactive, and feasible activities for meaningful student learning outcomes.
- Guided inquiry is most appropriate for effective use of the PhET simulations in the physics classroom as the simulation environments have the tendency to get learners

carried away by its interactive, pictorial, and colourful interface. The danger here is that without specific learning goals and some minimal level of guidance from teachers to facilitate the learning of the subject matter with PhETs, the simulation environment could be explored in ways that will not assist learners to learn meaningfully, but will only assist them in learning it as an ICT tool where they only explore the tabs, sliders and buttons in the sims environment technically, and not connect them to the physics content. It is therefore important to provide minimal level of guidance to ensure that learners' exploration of the PhETs are geared towards learning the subject matter (physics).

- For successful integration with the PhETs, ample time is essential to facilitate the teaching and learning process. This allows students to make sense of the simulation environment in relation to the subject matter and thus, promotes knowledge construction.

### **5.5.2. Technological pedagogical and content knowledge (TPACK)**

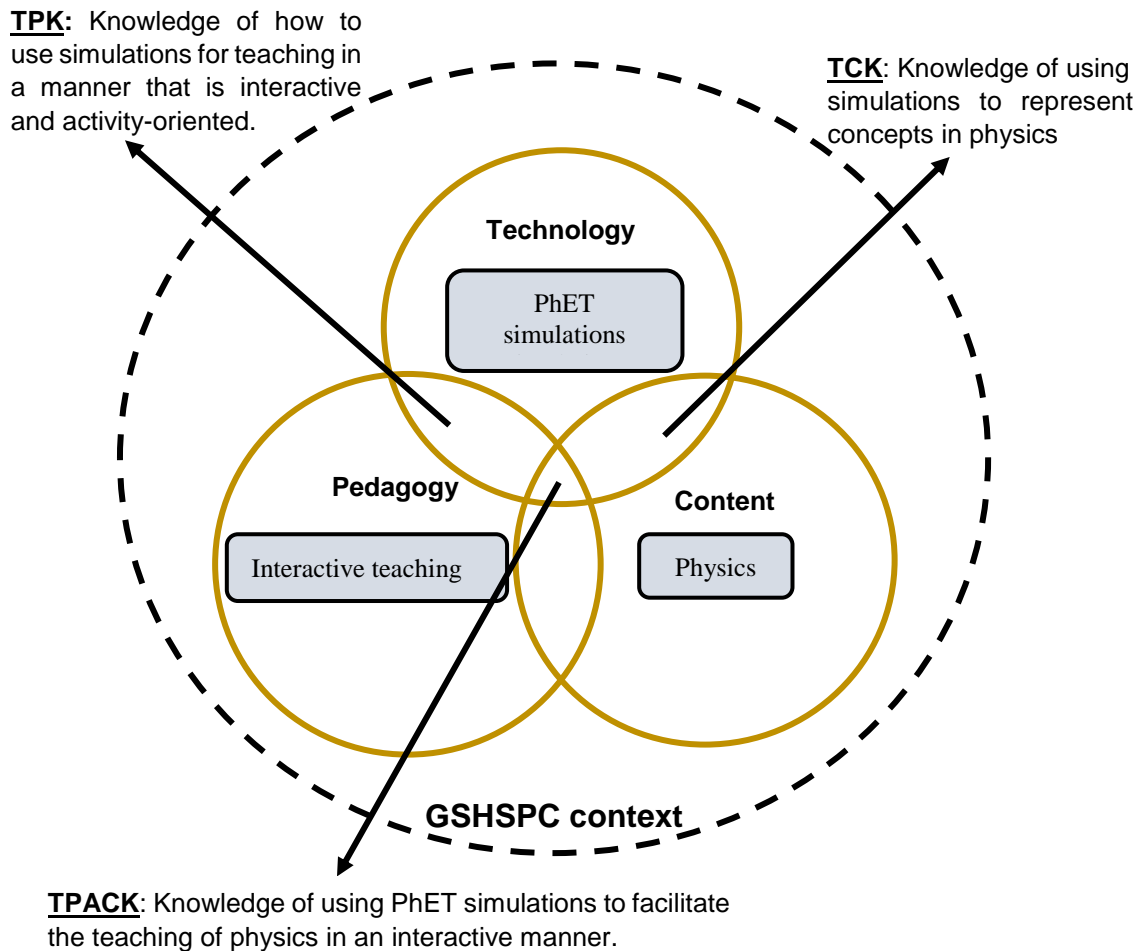
The current study used the TPACK framework to define and substantiate the kind of knowledge pre-service teachers need to drive interactive teaching and learning processes. It also served as the underlying theory for the preparation of pre-service teachers to effectively design and implement simulations-based lesson artefacts. In this regard, the TPACK framework was used for measuring the pre-service teachers' ICT-oriented knowledge and skills. The study focused on a PhET simulations application (representing the "T" component of the TPACK model) in realising interactive teaching prospects (representing the "P" component of the TPACK model) that are activity driven and student-centred in the teaching and learning of high school physics (representing the "C" component of the model).

It is apparent that the application of the TPACK framework helped the pre-service teachers in this study to develop their understanding of how technology could be used to present the subject matter in order to promote interactive teaching. Thus, the framework served as a useful lens through which the pre-service teachers' developed competencies

could be tracked in enabling a shift from the traditional teaching approach to a learner-centred teaching approach that is situated in a constructivist atmosphere.

While different studies in literature adapt either the transformative or integrative nature of the TPACK framework, this study places emphasis on the use of both transformative and integrative nature of the TPACK in the realisation of interactive teaching with ICT. The study contends that by combining both transformative and integrative views about nature of the TPACK, the pre-service teachers developed deeper understanding into the connections that exist between the subject matter, teaching strategies, and the ICT application; explaining the paradigm shift in their way of teaching.

Another important outcome of the study worth noting is the significant role “context” plays in the TPACK framework. As literature emphasise “context” as crucial for developing TPACK, it became necessary to modify the operationalised TPACK model (see Figure 2.3) as adapted in the study in order to lay emphasis on “context” (see Figure 5.1) since, “context” was not highlighted in the earlier operationalisation considered for the study in chapter 2; although, it was implied throughout the study. Figure 5.1 has been designed to include “context” which is interpreted to mean “Ghanaian Senior High School Physics Classroom” (denoted by GSHSPC as shown in Figure 5.1). This is to say that a consideration of the specific “context(s)” in which ICT is to be used is important for understanding and establishing the relationships that exist between and among the three knowledge domains of the TPACK model. Conceivably, context is essential for preparing pre-service teachers to effectively design, develop, and implement ICT-based lessons.



**Figure 5.1: Operationalised TPACK for study as situated in the Ghanaian Senior High School Physics classroom context.**

This study has also highlighted the importance of the interrelationships between teachers' knowledge about content and technology. The specific use of the PhETs simulation as the technological tool in this study helped to establish the reciprocal relationship in which the TCK domain of the TPACK framework is either technology- driven or content-driven. The study has demonstrated on one hand that for effective teaching with technology (PhETs), content is crucial for unfolding affordances of the technological tool. On the other hand, the study contends that for enhanced content knowledge, in-depth understanding of the affordances of technology is essential. This outcome of the study highlights the fact that not only does technology influences the subject matter in realising TCK, but also

adequate content on the part of teachers influences how the affordances of technology could be uncovered to bring into action TCK for effective teaching with ICT. This is what Mishra and Koehler (2006:1028) meant in their definition of TCK; that TCK represents the knowledge about the different ways in which “technology and content are reciprocally related”.

### **5.5.3. Five dimensions for meaningful learning with ICT (5DML-ICT)**

The use of the 5DML-ICT model (Howland et al., 2012) in formulating the conceptual framework was driven by the need to clearly define what interactive teaching is when situated in the constructivist ideologies for teaching and learning. For this purpose, the five dimensions for meaningful learning with ICT model was considered appropriate for characterising what interactive teaching should represent. This provided the means for measuring the “effectiveness” of the ICT (PhET simulations)-based intervention in the context of the study.

Deeper insights into the 5DML-ICT model has been provided by the study to emphasise that the combined effect of all the five dimensions for meaningful learning when incorporated in the design, development, and implementation processes of ICT-based interventions provokes interactivity in the teaching and learning of physics. Nevertheless, we find here that for the purpose of creating an interactive teaching and learner-centred environment with ICT, the *Cooperative* dimension of meaningful learning is not limited to providing platforms for divergent knowledge expressions as suggested by Koh (2013) as it also possesses the potential to inherently sustain the other four dimensions. With respect to the *Active* dimension, it is still not clear how it defines the *Constructive* dimension for interactivity to be attained as its implementation seemed difficult for the pre-service teachers in this study. These outcomes 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 with respect to the conceptual framework (see Figure 2.1) developed for this study in tracking and understanding pre-service teachers’ TPACK for interactive teaching and learning with ICT (simulations). These issues include:

1. Designing an ICT-based intervention to uniquely project the combined effect of all the dimensions of the 5DML-ICT model.
2. 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.
3. Characterising the *Active* dimension in the design process in such a manner that its relationship with the *Constructive* element of interactivity is clearly defined.

#### **5.5.4. PhET simulations as an interactive ICT tool for effective teaching and learning of high school physics**

In this study, PhET simulations represented the “T” component of the TPACK model, and was used as an interactive ICT tool because they are readily available, user friendly, content-based, and can be used offline on a computer. The study has shown that the PhET was useful not only for engaging the pre-service teachers in the design and teaching of interactive lessons, but also for helping them to develop their subject matter of the selected topics they taught much better. In whichever capacity the PhETs environment was adopted in the study, of most interest to the researcher was the extent to which it was effective (i.e., able to project the *Active*, *Constructive*, *Intentional*, *Authentic* and *Cooperative* dimensions of meaningful learning) in improving teaching and enhancing students’ learning of concepts in physics. The outcomes of the study have demonstrated this effectiveness in the way the PhETs promoted interactive teaching and meaningful learning of high school physics in the context of the study. The reasons for the effectiveness of the PhETs are explained in its:

- vehicular and rich catalytic characteristics which aided the pre-service teachers in the delivery of their respective interventions by use of an exploratory self-directed and a demonstrative form of inquiry in a constructivist environment.
- remarkable affordances as defined by its interactive interface which stimulated the pre-service teachers to assume the role of facilitators during the instructional process.

Furthermore, the study contends that for effective use of the PhETs, the following conditions are necessary:

- support structures (e.g., through facilitating modes such as the provision of summaries, engagement of learners' prior knowledge, supervision of learners' activities, and the creation of platforms for discussion) that are put in place.
- minimal level of guidance that is conditioned with elements such content-driving follow-up questions, instructions, snapshots from the simulation environment, and tables. These however are considered to be useful where activity sheets are involved in the ICT-based intervention.
- adequate time allocated for the delivery of the PhET-based physics lesson; in that time when limited, poses as a barrier to the effective use of the PhETs in the instructional process.
- availability of computer resources.

The PhET has also shown its potentials for facilitating students' conceptual change, motivating their interest in the subject matter, and engaging their attention throughout the instructional processes.

Another outcome identified with the use of the PhETs as the technological tool in this study is the inherent weaknesses it possesses that seem unique to its simulation environments or interfaces. Pre-service teachers in this regard had no control over the identified weaknesses. Thus, the study asserts that just like other ICT tools, the PhET tool poses as a barrier to the success of its own use in the physics classroom and that there is need for users to be mindful of the possible challenges it could pose in its use in learning the subject matter.

## **5.6. Implications and recommendations for practice, policy and future research**

The findings of this study have possible implications on practice, educational policy as well as future research.

### **5.6.1. Implications and recommendations for practice**

The findings of the study have implications for effective adaptation of the ICT-based interventions by practicing teachers.

The use of the PhETs as the interactive ICT tool for helping the pre-service teachers in the development of their competencies for integrating ICT into the teaching of high school physics emerged effective and appropriate in the Ghanaian context. This study therefore recommends that institutions mandated to train pre-service teachers consider adopting the PhETs as one of the major technological tools in the preparation of pre-service teachers to use ICT in the teaching of high school physics in Ghana. In-service training programmes for practicing physics teachers at the SHS levels could also 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 will be to promote interactive teaching of high school physics in Ghana by making use of the interactive learning environment the PhETs afford. This would also serve as a remedy for reducing the current teacher-centred approaches being adopted for teaching physics and curbing the problem of learner understanding and performance in physics in Ghana.

The use of an exemplary ICT-based resource that is theory-induced and developed to reflect the Ghanaian high school context in this study was found to be instrumental for helping the pre-service teachers gain insights into the needed underlying principles and conditions for their application in developing simulations-based physics lessons. The study advocates the incorporation of exemplary ICT-based curriculum materials into teacher training and professional development programmes for integrating ICT. Such an

initiative will provide pre-service and in-service teachers with authentic examples on how to effectively use ICT in their teaching practices. It will also serve as a model to guide them in the design of their own ICT-based lesson artefacts as well as inform their understanding of what ICT-based innovations constitute.

Design Team approach employed for the design and development of ICT-based interventions in this study proved to be an effective approach for developing pre-service teachers' competencies in the design and implementation of ICT-supported physics lessons. Hence, there is a need for teacher education institutions to consider adopting the Design Team approach in the training of pre-service teachers. This will provide a collaborative platform for teachers to learn from each other in learning with ICT and enforce a sense of interdependence and ownership among teachers.

The theoretical and conceptual bases considered for the present study were considered important for inspiring the development of the pre-service teachers' competencies in using ICT to teach in an interactive way. In light of this, the study recommends a consideration of theoretical frameworks as part and parcel of professional development arrangement for ICT integration as they are essential ingredients for equipping teachers with the needed ICT-oriented knowledge and skills that are not technocentric, but theory-induced and content-focused.

Both exploratory self-directed and the demonstrative forms of inquiry employed for the implementation of the ICT-based interventions were found in this study to be useful, purposeful, and interactive. However, these modes of delivery were also found to be classroom context-sensitive. The study therefore recommends that teachers be careful in assessing the resources available in their contexts in any attempt to adapt the ICT-based interventions designed in this study. In cases, where there are limited computer resources, as typical of most developing countries, the demonstrative form of inquiry is recommended as it provides an affordable and interactive platform for the lessons to be effective in situations where only the teacher has access to a computer.

At the teacher level, as the inherent weaknesses with the PhETs identified in the study are still existing and not yet resolved by developers, an in-depth exploration of selected PhET simulation environments prior to its use in the classroom is recommended. This is important for the discovery of the affordances as well as weaknesses in the PhETs; and crucial, as it could provide the teacher with valuable insights into various ways to design lesson activities in order to overshadow the weaknesses in the selected PhET simulation environment for enhanced learning outcomes.

### **5.6.2. Implications and recommendations for policy**

The findings of the study have implications for policy on teacher education and curriculum implementation.

At the SHS level, there seem not to be explicit guidelines of ICT use in practice for teaching the concepts in physics that have been enumerated in the curriculum and other policy documents. The Ghanaian physics curriculum for SHS does not seem to place much emphasis on the use of ICT in teaching physics. Findings of this study have pointed to the necessary next steps for integrating ICT in SHS in Ghana. The study supports the need to formulate, strengthen and enforce clear ICT policy implementation strategies regarding the practical use of ICT in the physics curriculum. When specific and effective ICT policies are put in place, ICT use will be promoted and enhanced to ensure that teachers integrate them effectively to bring about the desired improvements in teaching. In Ghana, curriculum developers and teacher education institutions may be better placed to spearhead this programme.

The study has shown that the ICT-based intervention developed was effective in improving teaching and enhancing students' learning of concepts in physics. As the teaching with ICT strives on availability and access to technological resource, there is need to improve access of ICT resources in Ghanaian SHS classrooms to ensure that teaching with ICTs are effective in yielding the desired results. The study therefore recommends that the Ministry of Education and other stakeholders consider prioritising

the provision of ICT resources in schools. This will ensure easy access and consequently, facilitate the integration of ICTs in the teaching and learning processes.

### **5.6.3. Implications for future research**

Although findings of this study have indicated that the ICT-based intervention developed in this study was effective among other things, in enhancing students' learning of concepts in physics, the question of whether the intervention will still be effective in promoting students' learning of physics in the actual Ghanaian SHS classroom still remains. This is because the learners used during the implementation of the intervention in this study were not actual SHS students, but instead pre-service teachers who mimicked the roles of SHS students. Hence, it would be valuable to take on further research to examine the effectiveness of the PhET simulations-supported physics lessons in the actual SHS physics classrooms in Ghana.

The study was limited to developing pre-service teachers' competencies for integrating ICT (PhET simulations) into the teaching of high school physics. Thus, it would be worthwhile to replicate the study for the development of pre-service teachers' competencies in integrating ICT into the teaching of other high school science subjects such as biology and chemistry; since the PhET environments are not limited to physics.

The participants of the current study were pre-service teachers that were either in their final or third year of the Science Education teacher preparation programme at the University of Cape Coast for the 2016/2017 and 2017/2018 academic years respectively. Currently, the first cohort of pre-service teachers have already been posted to various senior high schools in Ghana to pursue their professional carrier as teachers. The second cohort will follow suit in August, 2019. Therefore, it will be valuable to undertake a follow-up study on each of these cohorts of pre-service teachers to examine if the knowledge and skill gained in this study is being utilised in their teaching practices.

The study also has implication for future upgrade of the PhETs by its developers. In particular, the weaknesses identified with respect to the PhETs itself were found in this study to be software developer-related weaknesses since the pre-service teachers could not resolve issues that arose in this regard. The study therefore recommends further research studies with the intent to upgrade the PhETs. Such a study should seek to identify and resolve inherent weaknesses in the PhET interfaces which do not represent the subject matter accurately. For example, with the *Bending Light* PhET simulation, there is a need for developers of the PhETs to consider: a) modifying the calibration design of the virtual protractor feature to allow for clear and accurate readings; especially at intervals below 5 degree where the readings on the protractor currently seem very blur to an observer/learner and b) including an additional interactive tab or menu on the *Bending Light* simulation interface to help users/learners adjust the thickness of the monochromatic ray in order to facilitate accurate readings with the virtual protractor.

## **5.7. Conclusions**

The study has tracked the development of pre-service teachers' competencies for integrating ICT in the teaching of high school physics in Ghana by engaging eight pre-service teachers in a preparatory, extensive, and iterative process of design, development, and implementation of ICT-based interventions as situated in a Design-Based research approach. The process of design in this regard, called for an identification of a kind of ICT-based intervention with specific features to be modeled and developed by the pre-service teachers to meet the needs of the Ghanaian SHS physics classroom for the promotion of interactive teaching of physics. In this regard, the study identified inherent features such as PhET simulation environment, Interactive learning objectives, Technological pedagogical and content knowledge and the five dimensions for meaningful learning with ICT element, Activity sheet element, and lastly, Collaborative learning approach feature to represent the kind of ICT-oriented intervention that fit the realities in the Ghanaian SHS classroom for making the teaching of physics interactive.

Through the iterative process of design, development, and implementation of the ICT-based intervention, an understanding of how the pre-service teachers developed their ICT-oriented competencies for integrating ICT was generated. Also, insights on how the pre-service teachers improved upon their teaching to embrace interactive and learner-centred instructional strategies for meaningful learning experiences were developed with positive outcomes that situated:

- PhET simulations as an appropriate ICT tool for the Ghanaian SHS context based on its potential to cover specific topics in high school physics as well as support interactive teaching for meaningful learning outcomes.
- the ICT (PhET simulation-based) intervention to be effective in improving teaching and enhancing students' learning of concepts in physics.
- PhETs as an interactive ICT tool to facilitate conceptual change, development of understanding into various concepts in physics as well as stimulate learners' interest in learning concepts in physics.
- improvements in the pre-service teachers' teaching practices in their developed TPACK, improved content knowledge, and developed competencies in the exploration of the PhET simulations environment.

Despite these promising outcomes, the study unveiled some difficulties that the pre-service teachers encountered at the earlier stages of the design and implementation of the ICT-based intervention. These challenges suggested that there was a gap between theory and practice on the part of the pre-service teachers. This was reflected in their struggles in shifting from the teacher-dominated approach that they were deeply rooted in especially, at the initial stages of the programme. This places the initial training workshop of PDA as an important element in helping pre-service teachers to overcome challenges faced in the process of their development of competencies for the integration of ICT into their teaching practices as was the case of this study. The components of the PDA therefore became a capacity building block for grooming the pre-service teachers in developing the needed competencies for integrating ICT (simulations) into the teaching of physics in an interactive manner. Thus, the PDA employed in the study served as an effective strategy for equipping the pre-service teachers with the necessary knowledge

and skills they needed in order to overcome their earlier difficulties and to effectively and confidently use ICT in their teaching practices.

Prior exposure to elements such as the TPACK, five dimensions for meaningful learning with ICT theories as well as the adoption of a collaborative approach (e.g., Design Team approach) in a PDA reflects a possible remedy to Papert's (1987) concerns about the nature of professional development arrangements mostly organised for developing teachers' knowledge and skills on incorporating ICT. The author described such professional development as being purely technocentric; hinting that these arrangements usually focus only on the affordances and constraints of ICT, and the skills needed to operate them. Central to the effective tracking of the process of development of pre-service teachers' competencies for integrating ICT in teaching is the professional development arrangement component considered.

In concluding this research discourse, it is worthwhile to mention what I have learnt from the study during the research process. As a physics educator who is charged with the responsibility to train pre-service teachers to teach physics at the SHS level effectively, I have come to realise that ICT as an instructional tool is not an end in itself for effective teaching and learning in the physics classroom. Effective use of ICT is highly dependent on a teacher's: a) understanding of the affordances of ICT and its limitations in relation to a subject matter of interest; b) ability to make use of what a specific ICT tool affords in identifying the appropriate teaching strategy for presenting the subject matter; and c) ability to use a selected ICT tool to facilitate the teaching of the subject matter interactively. Competencies such as these do not come easily where ICT is involved; it requires comprehensive training that focuses not only on ICT skills acquisition, but also seeks to equip trainees with ICT-oriented teaching and learning competencies that are theory-informed and contextually sensitive.

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## APPENDICES

### APPENDIX A: SURVEY

#### A1: Pre-service teachers' evaluation questionnaire (TPACK self-assessment instrument)

##### Introduction

Dear student,

This questionnaire is designed to collect information about your knowledge and skills on integrating ICT in physics teaching. For the purpose of this questionnaire, technology refers to digital tools such as computers, laptops, Word processing packages, Graphical applications, Multimedia, interactive whiteboards, simulations software programmes, etc.

The information provided in this questionnaire will be used for reference only. All information will be treated with high confidentiality anonymity.

##### Personal Information

1. Your age .....
2. Sex: male [ ], female [ ]
3. Department .....
4. Program of study .....
5. Year of study.....
6. Level of Entry at UCC: Cert A [ ], SSS [ ], other, specify.....
7. Email .....
8. Phone number.....

##### Technology integration Knowledge and skills

Please indicate by circling whether you: Strongly Disagree (SD) = 1, Disagree (D) = 2, Not Sure (NS) = 3, Agree (A) = 4, or Strongly Agree (SA) = 5 to each of the following statements. In areas where you are uncertain of or neutral about your response, you may always circle "Not Sure"

		SD	D	NS	A	SA
<b>TK (Technology Knowledge)</b>						
1	I know how to solve my own technical problems.	1	2	3	4	5
2	I can learn technology easily.	1	2	3	4	5
3	I keep up with important new technologies.	1	2	3	4	5

4	I frequently play around the technology.	1	2	3	4	5
5	I know about a lot of different technologies.	1	2	3	4	5
6	I have the technical skills I need to use technology.	1	2	3	4	5
7	I have had sufficient opportunities to work with different technologies.	1	2	3	4	5
<b>PK (Pedagogical Knowledge)</b>						
8	I know how to assess student performance in a classroom.	1	2	3	4	5
9	I can adapt my teaching based-upon what students understand or do not understand.	1	2	3	4	5
10	I can adapt my teaching style to different learners.	1	2	3	4	5
11	I can assess student learning in multiple ways.	1	2	3	4	5
12	I can use a wide range of teaching approaches in a classroom setting (direct instruction, inquiry learning, participatory learning, problem/project-based learning, etc.).	1	2	3	4	5
13	I am familiar with common student understanding and misconceptions.	1	2	3	4	5
14	I know how to organize and maintain classroom management.	1	2	3	4	5
<b>CK (content Knowledge)</b>						
15	I have sufficient knowledge about physics.	1	2	3	4	5
15	I can use mathematics in explaining concepts in physics.	1	2	3	4	5
16	I have various ways and strategies of developing my understanding of physics.	1	2	3	4	5
17	I know about many applications of physics in real life.	1	2	3	4	5
18	I know concepts, facts, theories and procedures within physics.	1	2	3	4	5
<b>PCK (Pedagogical Content Knowledge)</b>						
19	I know how to select interactive teaching approaches to guide student thinking and learning of physics.	1	2	3	4	5
20	I have a curriculum knowledge about physics.	1	2	3	4	5
21	I know the aims and objectives for physics content.	1	2	3	4	5
22	I know instructional strategies that are suitable for physics concepts.	1	2	3	4	5
23	I know how and what to assess about students' physics learning.	1	2	3	4	5

<b>TCK (Technological Content Knowledge)</b>						
24	I know about technologies that I can use for understanding physics.	1	2	3	4	5
25	I know about technologies that I can use to enhance learning physics.	1	2	3	4	5
26	I can link appropriate technology to the physics content.	1	2	3	4	5
<b>TPK (Technology Pedagogical Knowledge)</b>						
27	I can choose technologies that enhance the teaching approaches for a lesson.	1	2	3	4	5
28	I can choose technologies that enhance students' learning for a lesson.	1	2	3	4	5
29	My teacher education program has caused me to think deeply about how technology could influence teaching approaches I use in my future classroom.	1	2	3	4	5
30	I am thinking critically about how to use technology in my future classroom.	1	2	3	4	5
31	I can adapt the use of the technologies that I am learning about to different teaching activities.	1	2	3	4	5
32	I can use technology for the creation of an interactive teaching and learning atmosphere.	1	2	3	4	5
33	I can use technology resources to facilitate higher order thinking skills, including problem solving, critical thinking, decision making knowledge, and creative thinking.	1	2	3	4	5
<b>TPACK (Technology Pedagogy and Content Knowledge)</b>						
34	I can teach lessons that appropriately combine physics, technologies and teaching approaches.	1	2	3	4	5
35	I can select technologies to use in my classroom that enhance what I teach, how I teach and what student learn.	1	2	3	4	5
36	I can use strategies that combine content, technologies and teaching approaches that I learned in my coursework/programme.	1	2	3	4	5

37	I can provide leadership in helping others to coordinate the use of content, technologies and teaching approaches at my school and/or district.	1	2	3	4	5
38	I can choose technologies that enhance the content for a lesson.	1	2	3	4	5

*Adapted from Schmidt, Baran, Thompson, Mishra, Koehler & Shin (2009a).*

**A2: Questionnaire to assess interactivity in pre-service teachers’ enactment of the ICT-based intervention (Five-dimension survey).**

**Introduction**

Dear student,

The following show various perceptions about the extent to which the five dimensions for meaningful learning with ICT was realised during the lesson enactment with simulations and the corresponding varying responses.

The information provided in this questionnaire will be used for reference only. All information will be treated with high confidentiality anonymity.

**Personal Information**

1. Your age .....
2. Sex: male [ ], female [ ]
3. Department .....
4. Program of study .....
5. Year of study.....
6. Level of Entry at UCC: Cert A [ ], SSS [ ], other, specify.....
7. Email .....
8. Phone number.....

**Five-dimension survey for interactivity**

Please indicate by circling whether you: Strongly Disagree (SD) = 1, Disagree (D) = 2, Not Sure (NS) = 3, Agree (A) = 4, or Strongly Agree (SA) = 5 to each of the following statements. In areas where you are uncertain of or neutral about your response, you may always circle "Not Sure"

	<b>Dimensions</b>	<b>SD</b>	<b>D</b>	<b>NS</b>	<b>A</b>	<b>SA</b>
<b>Active</b>						
1	The lesson activities allowed me to interact with the dynamics of a model physics system.	1	2	3	4	5
2	I used the simulation environment to work with subject matter half the lesson time.	1	2	3	4	5
3	Throughout the lesson period, I was highly engaged in exploring the various aspects of the simulation with my peers.	1	2	3	4	5
4	I used almost all the lesson time to explore the simulations environment working with the subject matter.	1	2	3	4	5
5	The lesson encouraged discussions with peers that allowed me to share my ideas.	1	2	3	4	5
6	The instructor facilitated discussions during the lesson rather than providing correct answers.	1	2	3	4	5
<b>Constructive</b>						
7	The simulations used in the lesson helped me to reproduce the subject matter.	1	2	3	4	5
8	The simulations-supported lesson articulated my personal understanding of the physics topic taught.	1	2	3	4	5
9	The lesson encouraged me to reflect on the physics concept that was being mimicked by the simulations	1	2	3	4	5
10	The lesson activities encouraged me to use sense-making and reasoning to interact with the simulations environment.	1	2	3	4	5
11	The simulations used in the lesson helped me to build on my prior knowledge and understanding of the subject matter.	1	2	3	4	5
12	The lesson allowed me to synthesize and describe key elements of a physics concept with the help of the simulation environment.	1	2	3	4	5
<b>Authentic</b>						

13	The simulations presented examples of physical phenomena related to the subject matter.	1	2	3	4	5
14	The simulations aided me to create multiple representations of the same physics concepts by manipulating some parameters while keeping another parameter constant.	1	2	3	4	5
15	By exploring a physical phenomenon with the simulations, I was able to identify a problem and propose solutions that were associated with the real-world and the subject matter.	1	2	3	4	5
16	The simulations helped me to represent my personal experiences of the real-world phenomenon in relation to the subject matter.	1	2	3	4	5
17	The simulations allowed me to form my own internal representations of physics concepts in a real-world phenomenon.	1	2	3	4	5
18	With the real-world experience with the simulations, concepts were well understood.	1	2	3	4	5
<b>Intentional</b>						
19	The lesson was structured with specific goals using the activity sheets.	1	2	3	4	5
20	The gaps in my knowledge of the subject matter were diagnosed by the instructor or peers.	1	2	3	4	5
21	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.	1	2	3	4	5
22	I used the simulation environment to self-diagnose different ways of learning and understanding the subject matter.	1	2	3	4	5
<b>Cooperative</b>						
23	Activities in the lesson promoted group work exploration of the simulation environment that required knowledge expressions of the subject matter.	1	2	3	4	5
24	The group discussions after each activity with the simulation environment was helpful in challenging my existing conceptions of the subject matter.	1	2	3	4	5
25	The group discussions after each activity with the simulation environment were helpful in modifying my existing conceptions of the subject matter were necessary.	1	2	3	4	5

26	Group activities in the lesson with the simulation environment allowed me to reflect, discuss and share ideas about the physics concept with other learners.	1	2	3	4	5
27	The group work brought about an atmosphere of trust among learners which gave me confidence to participate in all the activities.	1	2	3	4	5
28	The lesson encouraged learners to positively depend on each other through group work to achieve a mutual learning goal	1	2	3	4	5
29	The learner-facilitator interaction throughout the lesson was adequate.	1	2	3	4	5

*Adapted from Koh (2013).*

### **A3: Questionnaire on Student peers' experiences with ICT intervention (Student peers' survey)**

#### **Introduction**

Dear student,

This questionnaire is designed to examine your overall experiences about the lesson that was taught. In particular, how the simulations-based lesson aided your understanding of the physics concept taught is of much interest.

Be assured that the information you provide will be treated strictly confidential and will be used only for this research.

#### **Personal information**

1. Age: .....
2. Gender: Male [ ] Female [ ]
3. Topic treated in the lesson: .....

#### **Personal experience with intervention**

Please provide your genuine responses to each of the questions that follow by circling whether you: Strongly Disagree (SD) = 1, Disagree (D) = 2, Not Sure (NS) = 3, Agree (A) = 4, or Strongly Agree (SA) = 5 to each of the following statements. In areas where you are uncertain of or neutral about your response, you may always circle "Not Sure".

	<b>Experiences</b>	<b>SD</b>	<b>D</b>	<b>NS</b>	<b>A</b>	<b>SA</b>
1	The lesson was generally interesting.	1	2	3	4	5
2	The lesson explained concepts that I found difficult to understand before.	1	2	3	4	5
3	The content of the lesson was clear.	1	2	3	4	5
4	The content of the lesson was well understood.	1	2	3	4	5
5	The content of the lesson was well delivered.	1	2	3	4	5
6	The organization of the lesson is appropriate, logical and clear	1	2	3	4	5
7	I have learnt of something new which was not stated in the lesson outline.	1	2	3	4	5
8	The lesson delivery was exceptional	1	2	3	4	5
9	The group presentations were exciting	1	2	3	4	5
10	Due to clarity I can do my assignment with ease.	1	2	3	4	5
11	The use of the simulation and the power point presentation motivated my learning.	1	2	3	4	5
12	I found the lesson interactive.	1	2	3	4	5
13	There was clarification of some difficult concepts	1	2	3	4	5
14	Enjoyed the class and I wish such teaching with simulation will continue.	1	2	3	4	5
<b>Active</b>						
15	The demonstrations with the simulations environment helped me to understand more about the topic.	1	2	3	4	5
16	I had sufficient time to explore the simulations environment working with the subject matter.	1	2	3	4	5
17	The lesson activities allowed me to interact with the dynamics of a model physics system.	1	2	3	4	5
<b>Constructive</b>						
18	The lesson allowed me to synthesize key elements of the physics concepts with the simulation environment.	1	2	3	4	5

19	The simulation-based activities helped me to understand the lesson better.	1	2	3	4	5
20	The simulation environment used in the lesson helped me to reflect on my prior knowledge and made me understand the topic better.	1	2	3	4	5
<b>Authentic</b>						
21	I can relate concepts to real life application.	1	2	3	4	5
22	The use of activity sheet helped me to link the simulation environment to the subject matter.	1	2	3	4	5
23	The real real-world experience with the simulations, helped me to understand concepts better.	1	2	3	4	5
<b>Intentional</b>						
24	The activities in the lesson helped me to identify patterns and make generalisations.	1	2	3	4	5
25	The lesson was structured with specific goals using activity sheets.	1	2	3	4	5
26	The gaps in my knowledge of the subject matter were diagnosed by the instructor or peers.	1	2	3	4	5
<b>Cooperative</b>						
27	The team work helped me to understand better.	1	2	3	4	5
28	The lesson encouraged discussions with peers that allowed me to share my ideas.	1	2	3	4	5
29	Discussions in groups helped me to learn better.	1	2	3	4	5

*Adapted from Agyei (2012) and Koh (2013).*

**APPENDIX B: SEMI-STRUCTURED INTERVIEW PROTOCOL (adapted from Agyei (2012))**

**Personal information**

1. Name: \_\_\_\_\_
2. Teacher design team number \_\_\_\_\_
3. Topic taught: \_\_\_\_\_

**Planning and Preparation of Lesson**

4. What encouraged you to select this topic or concept for integration of simulations?
5. Are the simulations used in the lesson your own creation, or obtained from another source(s)?
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 initial training workshop influence your preparation to teach this content with simulations?

**During the lesson**

8. Do you think the learners like the approach? Why or why not?
9. What aspects of your teaching of the physics topic with simulations went well and supported student learning? Please explain.
10. What aspects of your teaching needed improvement?
11. How comfortable are you with using simulations in teaching physics?
12. What unexpected events happened when teaching this lesson with simulations?
13. What were the difficulties in guiding learners to use simulations with this physics lesson?
14. What role did you play in the teaching and learning process with the simulations? A facilitator or an impart of information.
15. Describe the learners' attention in this lesson? Were they engaged? Did they act differently than in regular lessons?
16. Describe how you engaged the learners using the simulation? No instruction, driving questions, gentle guidance or strong guidance and why?
17. What did the students say about learning with simulations in this physics lesson?

**Lesson Activities**

18. Was the activity sheet useful? Why and why not? Please explain.

19. How will you describe the lesson activities? Convergent or divergent; learner-centred or teacher-centred? Please explain.
20. Which of the five dimensions for meaningful learning with ICT do you think your lesson activities projected the most? Why and how?
21. In what way did the lesson activities encourage learners to collaboratively construct their understanding of the concept taught?
22. What elements in your lesson activities do you think promoted interactivity in the physics class.

**Post – review of teaching**

23. Do you think you gave minimal directions to the learners on the simulations use? If yes, how did it influence student's exploration and sense-making? Please explain. If no, why not?
24. Do you think the students' conceptual understanding of the physics focus of the lesson was improved with the integration of simulations? Please explain.
25. Was the integration of the simulations helpful in teaching the physics in an interactive manner in this lesson?
26. 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?
27. Will you teach other physics concepts using simulations? If so, which concept? If not so why not?
28. With the amount of physics content to be taught in the SHS each year, how often do you think it is feasible for you to incorporate spreadsheets in your lessons?
29. Do you think that more technology-oriented professional development programmes are needed to improve your teaching of physics with simulations?
30. What general comment can you make about using simulations in the SHS physics class?

## **APPENDIX C: SAMPLE QUESTIONS FOR FOCUS GROUP DISCUSSIONS**

1. Were the interventions appropriate for the physics topics selected for the lesson?
2. To what extent did the intervention promote interactivity during the lesson?
3. What weaknesses do you perceive in the simulations-supported interventions used in the lessons?
4. What strengths in the simulations-supported intervention do you think should be maximized for effective teaching of physics?
5. What can be done to improve the intervention?

## APPENDIX D: PhET SIMULATIONS-SUPPORTED PHYSICS LESSONS (PSSPLs)

### D1: Exemplary intervention 1

#### Lesson plan document

<b>Subject</b>	Physics	<b>School Level</b>	SHS 2
<b>Topic</b>	Wave motion	<b>Duration</b>	80 mins (approximately 2 periods)
<p><b><u>Overview of lesson:</u></b> In this lesson, the following support materials are developed for effective execution of the lesson. 1) PowerPoint slides —which the teacher will use to introduce the topic and also present summaries of lesson activities; 2) Lesson plan; which shows a step by step organization of the lesson to be conducted; 3) Student activity sheet; and 4) Assignment sheet. The activities for this lesson are developed based on a PhET simulation entitled: <i>waves-on-a-string</i>; and are designed in line with the lesson objectives and purposed to promote student-centred approach to teaching. Thus, the activity sheet for the lesson is designed to guide students in constructing their own knowledge.</p>			
<b>Specific Objectives</b>	<p>At the end of the lesson, students will be able to:</p> <ul style="list-style-type: none"> <li>▪ explain waves as a transfer of energy and not matter.</li> <li>▪ describe measurable waves properties such as amplitude and wavelength</li> <li>▪ describe how amplitude and wavelength affect waves.</li> </ul>		
<b>Interactive learning Objectives</b>	<p>At the end of the lesson, students will be able to use Physics Education technology (PhET) simulation entitled: <i>waves-on-a-string</i> guided by exploratory activities on waves, to</p> <ul style="list-style-type: none"> <li>▪ observe how energy is transferred when a string is wriggled at one end,</li> <li>▪ manipulate the various elements of the simulation to identify measurable properties of waves and</li> <li>▪ compare how the nature of the wave generated changes as one property is varied whilst, others are kept constant.</li> </ul>		
<b>Skills</b>	Students will use analytical, critical and observation skills to identify the measurable properties of waves.		
<b>Knowledge</b>	<p>Students will learn:</p> <ul style="list-style-type: none"> <li>▪ to define waves in their own words.</li> <li>▪ identify and describe two properties of a wave (amplitude and wavelength).</li> <li>▪ how each of these properties affect a wave motion.</li> </ul>		
<b>Attitude</b>	<ul style="list-style-type: none"> <li>▪ Creativity and critical thinking.</li> <li>▪ Collaboration: students to work together in groups in exploring the simulation environment and then discuss how well the subject matter is represented using the simulation environment.</li> </ul>		
<b>Prerequisite skills and knowledge</b>	<p>Students are able to:</p> <ul style="list-style-type: none"> <li>▪ identify the various parts of a wave.</li> <li>▪ state the types of waves.</li> <li>▪ identify the various media through which waves can propagate.</li> </ul>		

	<ul style="list-style-type: none"> <li>open a file on a computer by clicking on the file name or icon.</li> </ul>
<b>Classroom configuration for ICT (simulations) use</b>	Small groups (maximum of four students) in classroom or in computer laboratory.
<b>Resources</b>	<p><b>ICT:</b></p> <ul style="list-style-type: none"> <li>Simulations: PhET website – Waves-on-a- string (<i>for demonstration or group exploration</i>)  <a href="https://phet.colorado.edu/sims/wave-on-a-string/wave-on-a-string_en.html">https://phet.colorado.edu/sims/wave-on-a-string/wave-on-a-string_en.html</a></li> <li>Presentation software (Microsoft PowerPoint)</li> <li>Projector</li> <li>Computers in the classroom or computer laboratory</li> </ul> <p><b>NB:</b> This lesson assumes that there is no internet in the classroom or computer laboratory, thus, the teacher downloads the simulations onto the computers to be used offline in the classroom or computer laboratory prior to the lesson execution. However, the lesson can be adapted where there is access to internet in the classroom or computer laboratory as well as in a situation where only the teacher has access to a computer for demonstration.</p> <p><b>Online resources:</b>  Esler J. 2011. Waves properties with <i>waves on a string simulation</i></p> <p><b>Other resources:</b></p> <ul style="list-style-type: none"> <li>Pencil, paper, ruler, calculator</li> <li>Copies of activity sheets for each student or small group of students.</li> </ul>
<b>Lesson Plan</b>	
<b>Teacher Activity</b>	
<b>Student Activity</b>	
<b>Introduction</b> (time: 10 minutes)	<ul style="list-style-type: none"> <li>The teacher presents some test items (pre-test) on waves to students at the beginning of the lesson.</li> <li>By use of PowerPoint presentation, the teacher: <ul style="list-style-type: none"> <li>outlines lesson objectives to students.</li> <li>gives an overview of the lesson.</li> <li>direct students to open the simulations on their desktops by clicking on the waves-on-a string to introduce them to the PhET simulations offline (the PhET simulation are already downloaded and installed on the computers in the lab).</li> </ul> </li> </ul>
	<ul style="list-style-type: none"> <li>Students answer the test items based on their prior knowledge on waves.</li> <li>Students open the simulation on waves on their computer</li> </ul>

	<ul style="list-style-type: none"> <li>• The teacher asks students to open play with the simulation environment entitled <i>wave-on-a string</i> for about 5 minutes.</li> <li>•</li> </ul>	<ul style="list-style-type: none"> <li>• Students explore the PhET simulation environment (i.e., <i>wave-on-a-string</i>)</li> </ul>
<p><b>Main Activities</b> (<i>new knowledge, reinforcements, and reflections</i>)  (55 minutes)</p>	<p><b>Activity 1: Definition of waves (15 mins)</b></p> <ul style="list-style-type: none"> <li>• In order for students to construct their own knowledge of what waves are, the teacher guides students to do the following in groups of four: <ul style="list-style-type: none"> <li>• Set the simulations to a manual setting with the fixed end button on</li> <li>• Move the wrench at the left end of the string up and down</li> <li>• Observe the behaviour of the waves</li> <li>• Record their observations in relation to the medium of propagation of the wave generated and the how energy is transferred and the behaviour of the particles in the string</li> <li>• Explain waves in their own words</li> <li>• Identify the type of waves produced by the string.</li> </ul> </li> <li>• After <i>activity 1</i>, teacher asks each group to share their findings with the whole class for discussion.</li> </ul>	<ul style="list-style-type: none"> <li>• Students explore the simulations as guided by the teacher in groups and then answer the questions on activity sheet (<i>under activity 1</i>) based on their observations and newly acquired knowledge.</li> <li>• Students share ideas by discussing their answers to the questions under <i>activity 1</i> (see activity sheet) with their colleagues to finally come to a consensus on the definition of waves.</li> </ul> <p><b>Some discussion points expected from students:</b></p> <ul style="list-style-type: none"> <li>• The string is the medium of propagation of the wave generated</li> <li>• Energy is transferred from one point of the string to another but not matter</li> <li>• The particles in the string move upwards and downwards but once</li> </ul>

	<ul style="list-style-type: none"> <li>• Teacher then summarizes the key physics concepts in the activity.</li> </ul> <p><b>Activity 2: Measurable properties of waves (Amplitude) 20 mins</b></p> <p>To investigate the amplitude property using the simulation, wave-on-a -string, the teacher guides the students to do the following in groups:</p> <ul style="list-style-type: none"> <li>▪ Set the simulation environment such that the <i>pulse</i> button is on, <i>damping</i> slider is moved to the middle position, <i>tension</i> slider is also moved to the high position and the <i>ruler</i> option is checked.</li> <li>▪ Set the amplitude slider to vary from 0.25 to 1.25.</li> <li>▪ Measure the height of the wave generated at the start of its movement at each value of amplitude set.</li> <li>▪ Measure the distance the ring at the loose end of the string moves on the pole at each value of amplitude set.</li> <li>▪ Observe the nature of wave generated</li> <li>▪ Observe the how energy was transferred from one end of the string to the loose end of the string.</li> <li>▪ Predict the effect on height of the wave generated at the start of its</li> </ul>	<p>moved they return to their original equilibrium or rest position</p> <ul style="list-style-type: none"> <li>• A wave is a disturbance that is accompanied by the transfer of energy and travels through a medium from one point to another.</li> <li>• Students write down the key physics concepts in the activity, as teacher summarizes for revision purposes.</li> <li>• Students explore the simulations in accordance with the guidelines outlined by the teacher to investigate amplitude as a measurable property of waves, discuss their observations and then, answer the questions on work sheet that fall under <i>activity 2</i> (see activity sheet) based on their prior as well as newly acquired knowledge.</li> </ul>
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	<p><b>Activity 3: Measurable properties of waves –Wavelength (20 mins)</b></p> <p>To investigate the wavelength property of a wave using the simulation— <i>wave-on-a-string</i>, the teacher guides the students to do the following in groups:</p> <ul style="list-style-type: none"> <li>▪ Use a snapshot from the simulation environment to help students set up their simulation for <i>activity 3</i> in relation to the simulation elements such as amplitude, frequency, damping, tension and the ruler option.</li> <li>▪ Set the simulation to “<i>oscillate</i>” and “fixed end” mode.</li> <li>▪ Explore the simulation to try out the forward button</li> <li>▪ Explore the simulation to get a specific wave profile that looks exactly like a snapshot of the wave that has been pasted on the activity sheet under <i>activity 3</i> by the teacher</li> <li>▪ Observe the wave profile generated</li> <li>▪ Measure the distance between the first two crests— Wavelength (as indicated in the activity sheet for <i>activity 3</i> and labelled, A) with the help of the pause, forward buttons as well as the ruler in the simulation</li> <li>▪ Measure the distance between the last two troughs—Wavelength (as indicated in the activity sheet for <i>activity 3</i> and labelled B) with the help of the pause button, as well as the ruler in the simulation.</li> <li>▪ Identify similarities and difference in the wavelengths, A and B measured.</li> <li>▪ Define wavelength in terms of crests and troughs of a wave.</li> <li>▪ Solve problem on wavelength (indicated in activity sheet as <i>real-life application</i>)</li> </ul> <ul style="list-style-type: none"> <li>• After <i>activity 3</i>, teacher asks each group of students to share their findings with the whole class for discussion.</li> </ul>	<ul style="list-style-type: none"> <li>• Based on the snapshot which has been pasted in the activity sheet, students set up the simulation environment as guided by teacher in order to investigate <i>wavelength</i> as a measurable property of waves, discuss their observations and then, answer the questions on activity sheet that fall under <i>activity 3</i> based on their prior as well as newly acquired knowledge</li> </ul> <ul style="list-style-type: none"> <li>• Students share ideas about <i>wavelength</i> by discussing their answers to the questions under <i>activity 3</i> (see activity sheet) with their colleagues to finally come</li> </ul>
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	<ul style="list-style-type: none"> <li>• Teacher then calls a representative from each student group to present their findings on the applied question for whole class discussion.</li> <li>• Teacher then summarizes the key physics concepts in activity 3, and also, presents the solution for the applied</li> </ul>	<p>to a consensus about what <i>wavelength</i> is, and how it can be measure from a wave profile.</p> <p><b><i>Some expected discussion points:</i></b></p> <ul style="list-style-type: none"> <li>• The two distances are similar, in that they are all measuring the wavelength property of a wave.</li> <li>• However, they are different as one measures wavelength by two successive crests (distance A) and the other, by two successive troughs (distance B).</li> <li>• The <i>wavelength</i> of a wave is therefore, the distance between one crest and the next, or one trough and the next,</li> <li>• In order terms, the distance between two successive crests or troughs</li> <li>• The wavelength of a wave does not change, when measured by crests or troughs of the same wave profile.</li> <li>• A representative from each group of students presents the solution to the problem for whole class to discuss in order to come to a consensus about what the answer should be based on their prior and newly acquired knowledge on waves and its properties.</li> <li>• Students write down the key physics concepts in the activity as teacher</li> </ul>
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	question to students for them to compare with their solution to fill in the gabs.	summarizes for revision purpose and ask questions for more insights into the solution to the problem
<b>Conclusion</b> (15 mins)	<p>Finally, teacher sums up the whole lesson by highlighting the key concepts discussed as follows:</p> <ul style="list-style-type: none"> <li>• A wave is a disturbance that is accompanied by the transfer of energy and travels through a medium from one point to another.</li> <li>• A wave carries energy not matter but propagates through matter (for example a string as observed in the simulation).</li> <li>• Amplitude is the maximum or largest displacement of wave quantity (a particle on the medium) relative to the undisturbed, equilibrium position.</li> <li>• The amount of energy carried by a wave is dependent on the amplitude of the wave. The higher the amplitude the more energetic the wave generated becomes.</li> <li>• The <i>wavelength</i> of a wave is the distance between two successive crests or troughs. In simple terms, the distance the wave has travelled during one complete cycle.</li> </ul> <p>Teacher then ends the lesson by giving out</p> <ul style="list-style-type: none"> <li>• the same test items given to students at the beginning of the lesson for them to redo.</li> <li>• assignment sheets to students</li> </ul>	<p>Students take notes and then ask questions for more clarification where necessary.</p> <ul style="list-style-type: none"> <li>• Students redo the test as a way of assessing themselves on the physics concept discussed during the lesson.</li> <li>• Students take assignment sheets to be solved as homework.</li> </ul>

**Activity sheets for exemplary intervention 1**

**PHYSICS (SHS 2)**

**WAVE MOTION**

**Introductory Activity sheet (pre-test)**

1. Indicate whether the following statements are true or false
  - a. A wave is a disturbance that carries matter from one point to another in a medium. **True/False?**
  
  - b. A wave always moves through space. **True/ False?**
  
2. The following statements describe the various parts of a wave. Indicated in the blank space, the part of a wave that each statement best describes.
  - a. The original position of the medium of propagation of a wave  
.....
  
  - b. The highest point of the wave above line of origin.....
  
  - c. The distance between two consecutive lowest points of a wave below the line of origin; .....
  
  - d. The distance from the line of origin to the highest point of a wave above the line of origin .....
  
3. Draw a wave and identify the parts described in question 2 (a, b, c, and d) above.

## PHYSICS (SHS 2)

### WAVE MOTION

#### Main activity sheet

##### **Introduction**

In this activity sheet, you have been provided with three activities—activity 1, activity 2 and then, activity 3. These activities are designed based on the simulations on wave -on-a-string and are purposed to help you define waves using a common vocabulary; identify and explain the two measurable properties of wave—amplitude and wavelength; and then, apply your understanding of waves on a string to solve some problems in a real-life situation.

**Note:** *all activities are to be done in groups.*

##### **Activity 1: Definition of waves**

In this activity, you will explore the *waves-on-a string* simulation environment with the aim to define waves in simple terms.

##### **Directions for setting the simulation environment:**

- Set the simulations to the “manual” mode with the “fixed end” button.
- Afterwards, move the wrench up and down to generate a wave.
- Observe the behaviour of the waves generated as you move the wrench.
- Repeat with oscillate button on, observe the behavior of the waves generated.
- Record your observations by answering the following question:

1. What is the medium of propagation of the wave generated?

.....  
.....

2. How is energy transferred in the medium of propagation of the wave generated?

.....  
.....

3. What happens to the particles in the string as the wave is being generated?

.....  
.....

4. In simple terms, define waves in relation to *energy* and *matter*.

.....  
.....

5. What type of wave does a string produces?

.....  
.....

**Activity 2:** *Amplitude as a measurable property of a wave*

This activity is purposed to help investigate “amplitude” as one of the measurable properties of a wave.

**Directions for setting the simulation environment:**

Set the simulation environment such that the:

- *pulse* button is on,
- pulse width is set to 0.50 s
- *damping* slider is moved to the middle position,
- *tension* slider is also moved to the high position and
- the *ruler* option is checked. (hint: maintain these setting throughout this activity)

As you vary the amplitude from values of 0.25 cm to 1.25 cm at intervals of 0.25 cm (hint: move the amplitude slider to set these values) do the following:

- click the pulse icon on the simulation environment to generate a wave for each amplitude value,
- observe the wave, and then, answer the following questions below:

1. Based on your observations as you generate a wave at different values of the amplitude record your values in the table below.

<b>Amplitude (cm)</b>	<b>Height (in cm) of the wave generated at the start of its movement (<i>be sure your ruler is lined up correctly</i>)</b>	<b>Distance (in cm) the ring at the loose end of the string moves on the pole</b>
0.25		
0.50		
0.75		
1.00		
1.25		

2. As amplitude increases, what happens to the height of the wave generated at the start of its movement?

.....  
.....

.....  
.....

3. What does the height of the wave generated represent?

.....

4. As amplitude increases, what happens to the distance the ring moves on the pole?

.....  
.....  
.....  
.....

5. How is energy affected as you vary the amplitude of a wave?

.....  
.....  
.....  
.....

6. What is “*amplitude*”?

.....  
.....  
.....  
.....

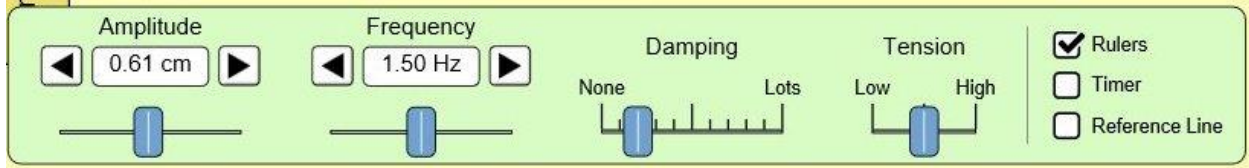
7. Draw a wave and identify the amplitude of the wave.


**Activity 3: *Wavelength as a measurable property of a wave***

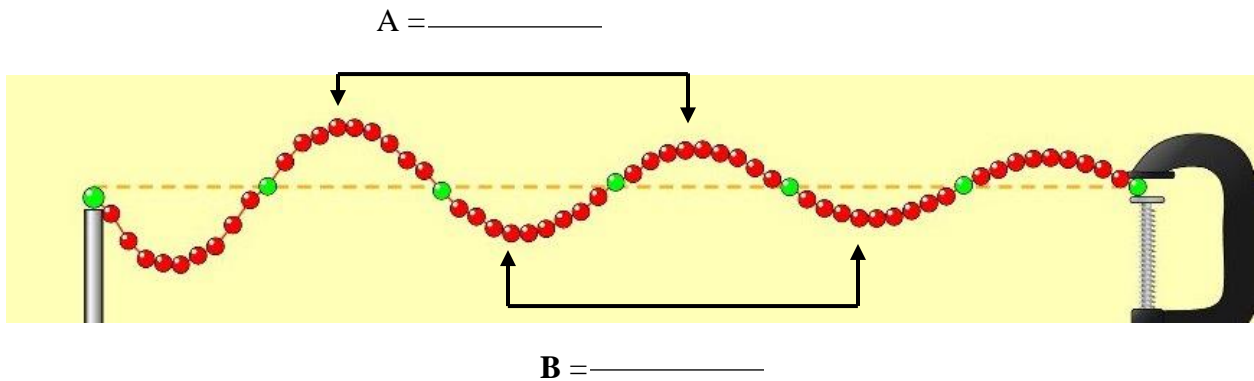
In this activity, our aim is to investigate “Wavelength” as one of the measurable properties of a wave.

***Directions for setting the simulation environment:***

- Set the simulation environment like the picture below:



- Select the oscillate and fixed end button on the screen to run the simulation.
- Explore the simulation to try out the forward button .
- Explore the simulation to get a specific wave profile that looks exactly like the picture below (*the pause and forward button may be useful*).
- Observe the wave generated on your screen
- Measure the wavelengths, A and B from the simulation environment (use the ruler in the simulation) and answer the following question in relation to the picture below:



1. From your simulation, what is the \_\_\_\_\_ value for the wavelength labeled A in the picture? Write your answer in the space provided on the picture above.
2. From your simulation, what is the value for the wavelength labeled B in the picture? Write your answer in the space provided on the picture above.

3. How similar is wavelength A to wavelength B?

.....

.....

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.....

4. How different is wavelength A from wavelength B?

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.....

5. What is “*wavelength*”?

.....  
.....  
.....  
.....

**Real-life application**

A string is plucked such that 1.5 waves are generated as energy is carried from point A of the string to point B of the string.

a. Draw the wave profile.

b. If the distance from point A to point B is 60 cm, then the wavelength is?

.....

**PHYSICS (SHS 2)**

**WAVE MOTION**

**Assignment Sheet**

On separate sheets of graph paper, draw four different waves with the following measurements. Label the parts of the wave drawn and include the measurements.

Wave number	Crests	Troughs	Wavelength
1	1.0 cm	1.0 cm	2.0 cm
2	3.5 cm	3.5 cm	2.5 cm
3	0.5 cm	0.5 cm	3.0 cm
4	2.0 cm	2.0 cm	0.5 cm

State which wave you think has the highest amplitude. Explain the reasons for your selections.

## D2: Exemplary intervention 2

### Lesson plan document

<b>Subject</b>	Physics	<b>School Level</b>	SHS 2
<b>Topic</b>	Thin lenses	<b>Sub Topic</b>	Formation of images by a bi-convex thin lens (converging lens)
<b>Duration</b>	80 mins (approximately 2 periods)		
<b>Overview of lesson:</b> In this lesson, the following support materials are developed for effective execution of the lesson. 1) PowerPoint slides —which the teacher will use to introduce the topic and also present summaries of lesson activities; 2) Lesson plan; which shows a step by step organization of the lesson to be conducted; 3) Student activity sheet; and 4) Assignment sheet. The activities for this lesson are developed based on a Physics Education Technology (PhET) simulation entitled: <i>Geometric Optics</i> and are designed in line with the lesson objectives and purposed to promote student-centred approach to teaching. Thus, the activity sheet for the lesson is designed to guide students in constructing their own knowledge.			
<b>Specific Objectives</b>	At the end of the lesson, students will be able to: <ul style="list-style-type: none"><li>▪ describe the characteristics of the image formed by a converging lens at different object positions.</li><li>▪ describe how the curvature radius of a converging lens affects the nature of images formed.</li></ul>		
<b>Interactive learning Objectives</b>	At the end of the lesson, students will be able to use and explore the PhET simulation environment to: <ul style="list-style-type: none"><li>▪ observe how a change in the position of an object placed before a converging lens determines:<ul style="list-style-type: none"><li>➢ the location of the image formed.</li><li>➢ the nature of the image formed.</li></ul></li><li>▪ determine how varying values of the curvature radius affects the kind of image formed by a converging lens at constant lens diameter as well as refractive index.</li></ul>		
<b>Skills</b>	Students will develop their analytical, critical and observation skills to: <ul style="list-style-type: none"><li>▪ identify and describe the characteristics of the images formed by a converging lens at different object positions.</li><li>▪ describe how the curvature radius of a converging lens influences the nature of image formed.</li></ul>		
<b>Knowledge</b>	Students will learn: <ul style="list-style-type: none"><li>▪ to trace light rays to locate positions of images formed by a converging lens</li><li>▪ about the characteristics of the image formed by a converging lens at different object positions.</li><li>▪ about how the curvature radius affect the lens action.</li></ul>		

<b>Attitude</b>	<ul style="list-style-type: none"> <li>▪ Creativity and critical thinking.</li> <li>▪ Collaboration: students to work together in groups to explore and interact with the simulations environment as the teacher demonstrates and then, discuss how well the subject matter is represented using the simulation environment.</li> </ul>	
<b>Prerequisite skills and knowledge</b>	<p>Students are able to:</p> <ul style="list-style-type: none"> <li>▪ explain refraction of light.</li> <li>▪ sketch and describe the three major special rays that are used to locate the images formed by converging lenses.</li> <li>▪ define a lens.</li> <li>▪ identify the various parts of a lens.</li> <li>▪ describe the terminologies associated with lenses.</li> <li>▪ differentiate between a virtual and real image.</li> <li>▪ measure length using a ruler.</li> </ul>	
<b>Classroom configuration for ICT (simulations) use</b>	Small groups (maximum of four students) in classroom or in computer laboratory.	
<b>Resources</b>	<p><b>ICT:</b></p> <ul style="list-style-type: none"> <li>• Simulations: PhET website – <i>Geometrical Optics (for demonstration or group exploration)</i>  <a href="https://phet.colorado.edu/sims/wave-on-a-string/wave-on-a-string_en.html">https://phet.colorado.edu/sims/wave-on-a-string/wave-on-a-string_en.html</a></li> <li>• Presentation software (Microsoft PowerPoint)</li> <li>• Projector</li> </ul> <p><b>NB:</b> This lesson has been designed to fit the classroom situation where there is no internet and only the teacher has access to a computer; thus, the teacher downloads the simulations onto the available computer prior to the lesson execution, to be used offline in the classroom for demonstration. The lesson can be adapted in situations where there is access to internet and a computer laboratory/classroom with computers for students.</p> <p><b>Other resources:</b></p> <ul style="list-style-type: none"> <li>• Pencil, paper, ruler, calculator</li> <li>• Copies of activity/assignment sheets</li> </ul>	
<b>Lesson Plan</b>		
<b>Teacher Activity</b>		<b>Student Activity</b>
<b>Introduction</b> (time: 15 minutes)	<ul style="list-style-type: none"> <li>• Teacher presents pictures about concepts in physics that are associated with refraction of light and thin lenses for students to identify, discuss the concepts in physics they illustrate and then answer the questions on the introductory activity sheet under <i>Introductory Activity 1</i>.</li> </ul>	<ul style="list-style-type: none"> <li>• Students observe the pictures presented, discuss their ideas in groups based on their prior knowledge on refraction of light and thin lenses and then answer the questions on the introductory</li> </ul>

	<ul style="list-style-type: none"> <li>• Teacher then explains to students how these concepts inform the topic of the day.</li> <li>• By use of Microsoft PowerPoint presentation software, teacher: <ul style="list-style-type: none"> <li>- outlines lesson objectives to students.</li> <li>- gives an overview of the lesson, placing emphases on how the demonstration aspect of the lesson will be done.</li> <li>- explains the group arrangement for the lesson to students.</li> <li>- introduces students to the PhET simulations (entitled <i>Geometric Optics</i>) environment employed for lesson.</li> <li>- gives an overview of the lesson activities and how each activity on the activity sheet will be executed.</li> </ul> </li> <li>• Teacher projects the simulation on the board and allows students to observe and make sense of the interactive features of the simulations for about 5 minutes.</li> <li>• Teacher then asks students to answer questions on the introductory activity sheet under <i>introductory activity 2</i> (in groups) after observing and making sense of the simulation environment in order to identify the features of the simulation and hence, indicate their respective functions based on their prior knowledge on converging lens.</li> <li>• Teacher leads students to summarize <i>introductory activity 2</i> by calling each group leader to demonstrate his or her group predictions about the features of the simulation in relation to converging lens to the class. (<i>here the teacher asks one or two questions to test students understanding of</i></li> </ul>	<p>activity sheet under <i>Introductory Activity 1</i></p> <ul style="list-style-type: none"> <li>• Students discuss (in groups) the interactive features of the simulation environment and then brain storm to make predictions about the functions of each feature they observe based on their prior knowledge on converging lens.</li> <li>• Students work in groups to answer the questions on the introductory activity sheet (under <i>introductory activity 2</i>) based on their prior knowledge on converging lens.</li> <li>• Students ask questions about each groups' prediction on the aspects of converging lens the simulation mimics and then, try to come to a consensus</li> </ul>
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	<p><i>physics concepts being projected as the leader explores the simulation environment by demonstration).</i></p> <ul style="list-style-type: none"> <li>• Teacher ends the introductory session with a detailed demonstration of how each feature in the simulation environment functions to enable the formation of images by use of a converging lens.</li> </ul>	<p>about the correct functions of the simulation features.</p> <ul style="list-style-type: none"> <li>• Students match their group findings to the teacher's demonstrations to fill in the gaps in their constructed knowledge about image formation by converging lens.</li> <li>• Students ask questions where necessary to get better understanding of the key physics concepts.</li> </ul>
<p><b>Main Activities</b> (<i>new knowledge, reinforcements, and reflections</i>)  (55 minutes)</p>	<p><b>Activity 1: Characteristics of images formed by a converging lens via ray diagrams (25 mins)</b></p> <p>In this activity, the teacher guides students by the use of the PhET simulation (through demonstration and activity sheet) to help students construct their own knowledge. In particular, teacher guides students to do the following:</p> <ul style="list-style-type: none"> <li>• Observe, identify and describe the nature of various images formed by a converging lens as different objects are placed in front the lens at different positions on the principal axis. Specific areas to be considered I include positions: <ol style="list-style-type: none"> <li>1. within the focal length (i.e., between the focal point and the optical center of the converging lens lens).</li> <li>2. at the focal point.</li> <li>3. beyond the focal point.</li> </ol> </li> <li>• Make predictions about the position and characteristics of the image that will be formed supposed an object was placed at an infinite distance from the lens.</li> </ul>	<ul style="list-style-type: none"> <li>• Students will observe, discuss and make sense of the demonstrations made by the teacher or their colleague student using the simulations (in groups), and then answer the questions under <i>activity 1</i> (See activity sheet) based on their observations and newly acquired knowledge.</li> <li>• Students discuss based on their observations and newly acquired knowledge in order to come to consensus about where the image is formed and also, make predictions about its characteristics. This will be done in groups.</li> </ul>

	<ul style="list-style-type: none"> <li>• Come out with a sketch, (using ray diagrams and special rays) of how the image will be formed at an infinite distance away from the lens; showing its characteristics.</li> </ul> <p>After <i>activity 1</i>, teacher asks each group to share their observations, findings and predictions with the whole class for discussion.</p>	<ul style="list-style-type: none"> <li>• Students draw on activity sheet under <i>Activity 1</i> a ray diagram to show where and how the image will be formed at an infinite object position from the lens using their prior knowledge about special rays and experiences with the simulation environment.</li> <li>• Students share ideas by discussing their answers to the questions under activity 1 with their colleagues to finally come to a consensus on the characteristics of the images formed at each object position and also, decide on whether a change in object at the different positions as outlined and demonstrated by the teacher has any effect on the characteristics of the images formed by a converging lens.</li> </ul> <p><b><i>Some discussion points expected from students:</i></b></p> <ul style="list-style-type: none"> <li>• At an object position within the focal length, the image formed is       <ol style="list-style-type: none"> <li>1. virtual</li> <li>2. larger than object (magnified)</li> <li>3. upright</li> </ol>       Also, light rays appear to converge on the same side of the lens as the object and hence, the lens is a magnifying glass.     </li> </ul>
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	<p>Teacher then summarizes the key physics concepts in the activity (i.e., <i>Activity 1</i> on activity sheet).</p>	<ul style="list-style-type: none"> <li>• At the focal point, no image is formed (in other words, the image is assumed to be formed at infinity)</li> <li>• At a position beyond the focal point, the image is:             <ol style="list-style-type: none"> <li>1. real.</li> <li>2. Inverted.</li> <li>3. larger than object if object is within two focal lengths of the converging lens.</li> <li>4. smaller than object if object is a distance greater than two focal lengths away.</li> </ol> </li> </ul> <p>Also, light rays converge on the opposite side of the lens and can be focused on a screen.</p> <ul style="list-style-type: none"> <li>• At an infinite distance from the converging lens, parallel rays of light converge at the focus. Thus, the image is formed at the focal point.</li> <li>• A change in the object does not affect the position or nature of images formed by a converging lens as long as the position of the object is the same.</li> <li>• Students write down the key physics concepts in the activity, as teacher summarizes for revision purposes.</li> </ul>
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	<p><b>Activity 2: Lens property—Curvature radius (30 mins)</b></p> <p>This activity is purposed to investigate the effects of the lens curvature radius on the nature of image formed at a specific position of the object using the PhET simulation—<i>Geometric Optics</i>.</p> <p>By setting the simulation environment such that the <i>refractive index</i> slider as well as <i>diameter</i> slider are kept at constant values of 1.5 and 1.3 m respectively, teacher guides the students to do the following in groups via demonstrations:</p> <ul style="list-style-type: none"> <li>• Observe the dynamics in the simulation environment as the curvature radius is altered using the curvature radius slider in order to define curvature radius in their own simple words as in <i>activity 2</i> (see activity sheet).</li> <li>• Observe the variations in the simulation environment and answer questions under <i>activity 2</i> (see activity sheet) in relation to how variations in the curvature radius (from 0.3 m to 0.9 m at intervals of 0.3 m) affect the relationship between an object (placed at a specified position) and the nature of image formed by the converging lens.</li> <li>• Describe the nature of images formed for each curvature radius as outlined under <i>activity 2</i> provided by the teacher.</li> <li>• Make comparisons between the nature of the images formed at different values of the curvature radius.</li> <li>• Predict, based on their observations and interaction with the simulations environment, how the Curvature radius influences the position, type and nature of image formed by a converging lens when object is place at the same position varying the curvature radius</li> </ul> <p>After <i>activity 2</i>, teacher asks each group to share their findings about curvature radius as a lens property of the converging lens as well as its influence on the nature of image formed with the whole class for discussion.</p>	<ul style="list-style-type: none"> <li>• Students observe teacher or colleague student as he/she explores the simulations (through demonstrations) in accordance with the guidelines outlined by the teacher to define curvature radius; investigate curvature radius as a measurable lens property; and then discuss (in groups) their observations as well as answers to the questions on activity sheet that fall under <i>activity 2</i> based on their prior as well as newly acquired knowledge and experiences with the simulation environment.</li> <li>• Students share ideas by discussing their answers to the question indicated on the activity sheet (under <i>activity 2</i>) with their colleagues to</li> </ul>
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	<ul style="list-style-type: none"> <li>• Teacher summarizes the key physics concepts in <i>activity 2</i>.</li> </ul>	<p>finally come to a consensus on what curvature radius is, and how it affects the nature/characteristics of image formed when varied.</p> <p><b>Some expected discussion points include:</b></p> <ul style="list-style-type: none"> <li>• As the lens curvature radius is increased from 0.3 m to 0.9 m at intervals of 0.3, the       <ol style="list-style-type: none"> <li>1. lens grows thinner (becomes less rounded).</li> <li>2. focal length increases</li> <li>3. size of image changes</li> <li>4. position of image changes</li> </ol> </li> </ul> <p>Thus, curvature radius has an effect on the size of the lens itself, the focal length of the lens, the size and position of the image formed.</p> <ul style="list-style-type: none"> <li>• Students write down the key physics concepts in the activity as teacher summarizes for revision purposes and then ask questions where necessary for better understanding.</li> </ul>
<p><b>Conclusion</b> (15 mins)</p>	<ul style="list-style-type: none"> <li>• Teacher asks students questions about how the concept of converging lens is being applied in their daily life.</li> <li>• Teacher sums up the lesson by asking questions to test students' understanding of</li> </ul>	<ul style="list-style-type: none"> <li>• Students share their experiences with the class for a short discussion.</li> <li>• Students ask questions for more clarification</li> </ul>

	<p>the physics concepts thought/ discussed on thin lenses during the lesson and then throws more light on how converging lens is being applied in our daily life.</p> <ul style="list-style-type: none"> <li>Finally, the teacher ends the lesson by giving assignment sheets to students to be done as a home work.</li> </ul>	<p>where necessary and then, answer questions posed by the teacher.</p> <ul style="list-style-type: none"> <li>Students take assignment sheet to be answered later.</li> </ul>
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**Activity sheets for exemplary intervention 2**

**PHYSICS (SHS 2)**

**FORMATION OF IMAGES BY A CONVERGING LENS**

**Introductory Activity sheet**

**Introductory activity 1**

Based on your prior knowledge on refraction of light and thin lenses, answer the following questions with reference to the pictures and figures shown on the PowerPoint slide.

***NB: This activity is to be done in groups.***

1. What do the pictures labeled **A**, **B**, **C** and **D** on the slide 2 represent? Indicate your answer below:

**A** ..... **B** .....

**C**..... **D**.....

2. What is the difference between picture **A** and picture **C**?

.....  
 .....  
 .....

3. From figure **E** (on the PowerPoint slide), what is the name given to the special rays labelled **1**, **2**, and **3**?

.....

4. From the ray diagram (labelled **E** on PowerPoint slide), explain in simple terms what the special rays labelled **1**, **2**, and **3** depict respectively.

Special ray 1: .....

.....

Special ray 2: .....

.....

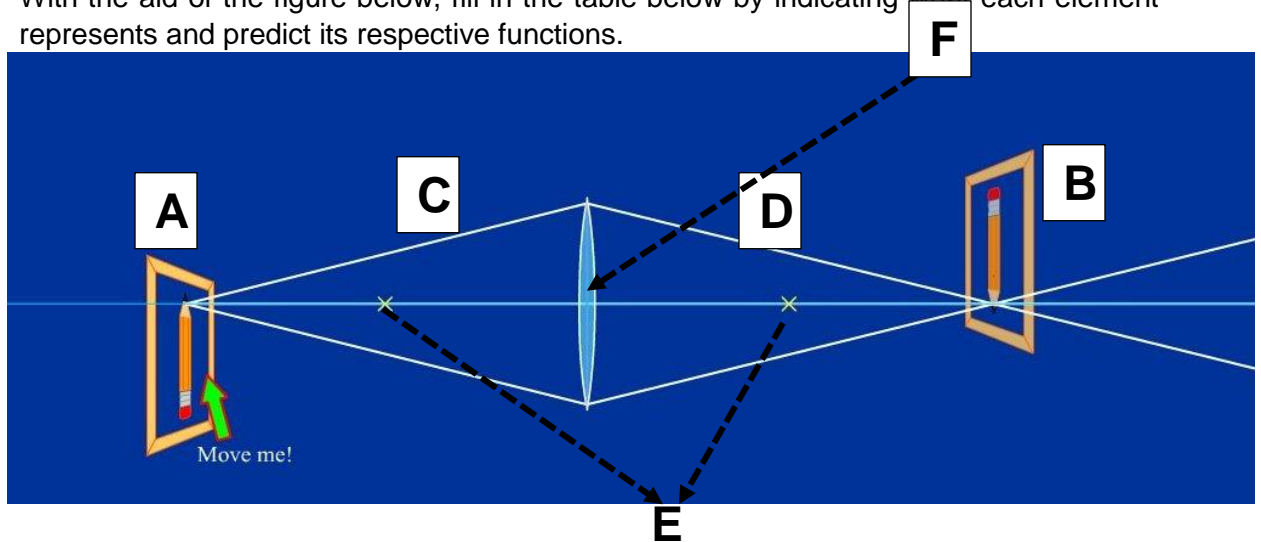
Special ray 3: .....

### Introductory activity 2

The following pictures are snapshots of some of the elements from the simulation projected on the board. In this activity, you are required to

- identify and make predictions about how each of the elements in the PhET simulation environment entitled *Geometric Optics* functions based on your prior knowledge on thin lenses.
- discuss and answer the questions in this activity in groups.

1. With the aid of the figure below, fill in the table below by indicating what each element represents and predict its respective functions.



Label of element in simulation	What the element represents	Function/purpose of element in the simulation environment
A		
B		
C		

<b>D</b>		
<b>E</b>		
<b>F</b>		

2. By observing the simulation environment, predict the implication of each of the elements indicated below to the lens action as depicted by the simulation.



H: .....

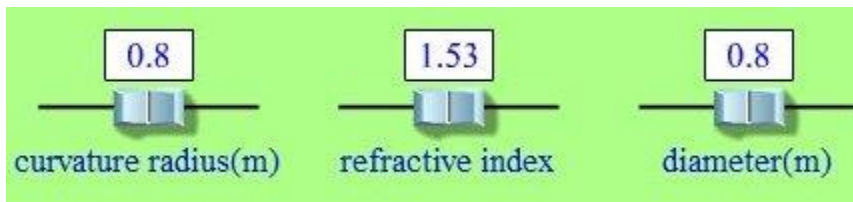
G: .....

K: .....

.....

.....

3. Below are sliders used in the simulation environment to represent curvature radius, refractive index and diameter of a lens, predict how each of these sliders could be used in the simulation and the purpose for its use.



Curvature radius: .....

.....

.....

Refractive index: .....

.....

.....

*Diameter.* .....

.....

.....

## PHYSICS (SHS 2)

### FORMATION OF IMAGES BY A CONVERGING LENS

#### Main activity sheet

#### **Introduction**

In this activity sheet, you have been provided with two activities—activity 1 and activity 2. These activities are designed based on the simulations entitled: *Geometric Optics* and through demonstration exercises, are purposed to help you to:

- identify and describe the characteristics of the images formed by a converging lens (bi-convex lens) at different positions of an object placed in front of the lens; and also,
- explain how a lens property such as curvature radius affect the nature of images formed by a converging lens.

Note: all activities are to be done in groups.

#### **Activity 1: Characteristics of images formed by a converging lens via ray diagrams (25 mins)**

Based on your observations of the demonstration exercises using the simulation, discuss in groups to answers the following questions:

#### **Q1.**

a. Indicate where the image is formed at the following object positions:

- i. Between the focal point and the optical center

.....

- ii. At the focal point

.....

- iii. Beyond the focal point

.....

b. Fill in the table below to describe the characteristics of the image formed at each of the positions indicated in question 1a.

Object position	Image position	Characteristics/nature of imaged formed
Within focal length		
At the focal point		
Beyond the focal point		

--	--	--

**Q2.**

If the object was to be changed from a pencil to a star, would there be a change in the image positions using the same object positions indicated in question 1 above? Explain your answer.

.....

.....

.....

**Q3.**

What will be the position and characteristics of the image formed supposed an object was placed at an infinite distance from the lens? Explain your answer with the aid of a diagram (NB: *Answer in the space provided below*).

**Activity 2:** Lens property—*Curvature radius*

This activity is purposed to investigate the effect of the curvature radius on the nature of image formed at different positions of the object using the simulation—*Geometric Optics*.

Based on your observations of the demonstration exercises using the simulation, discuss in groups and provide answers to the following questions:

1. Describe how the bi-convex lens used in the simulation behaves as the *curvature radius* slider is altered from one value to another.

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.....

2. In simple terms, define curvature radius based on the dynamics in the simulation environment as the *curvature radius* slider is altered in question 1.

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.....

3. An object is placed at a constant position beyond the focal point with the curvature radius being altered from 0.3 m to 0.9 m at intervals of 0.3 m using the simulation environment. Based on your experiences with the simulation do the following:

- i. Write your observations about the position and size of object and image formed at each value of the curvature radius in the table below.

Curvature radius (m)	Object		Image	
	Position	Size	Position	Size
0.3				
0.6				

0.9				

- ii. What conclusion can you draw from your observations in question 3i to explain how the variations in the curvature radius influences the relationship between object and image formed?

.....

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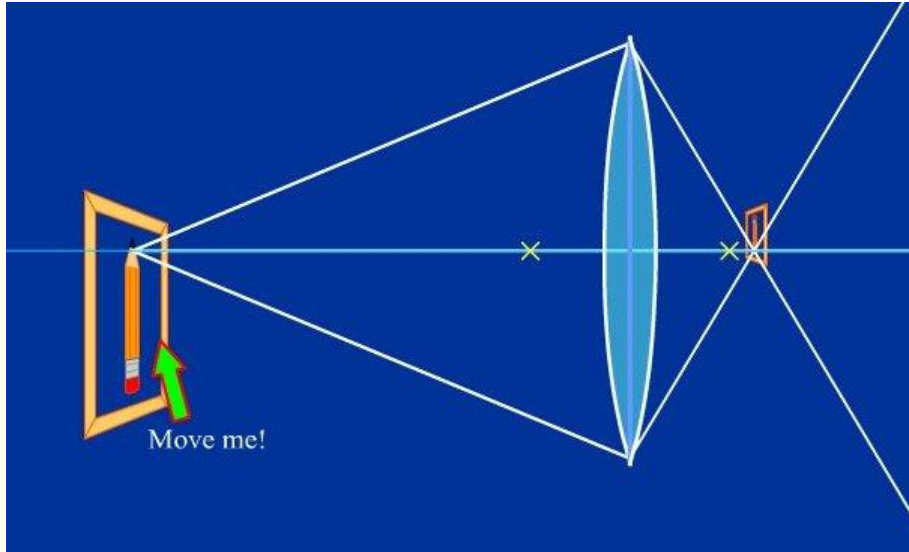
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4. **A)** The pictures below are snapshots from the simulation environment as the curvature radius is varied from 0.3 m to 0.9 m at intervals of 0.3 m keeping the refractive index as well as lens diameter at constant values as seen in the demonstrations made in class.
- Use a ruler to measure the focal length, object height, object distance, image height, and image distance (in units of cm) from the snapshots of the simulation indicated below.
  - Write your values in the space provided on the left side of the snapshots.

**At curvature radius of 0.3 m**



Focal length .....

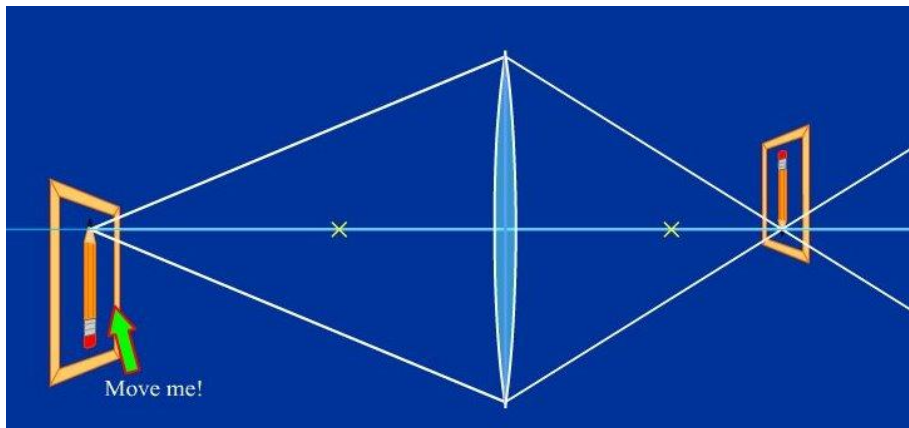
Object height .....

Object distance .....

Image height .....

Image distance.....

**At curvature radius of 0.6 m**



Focal length .....

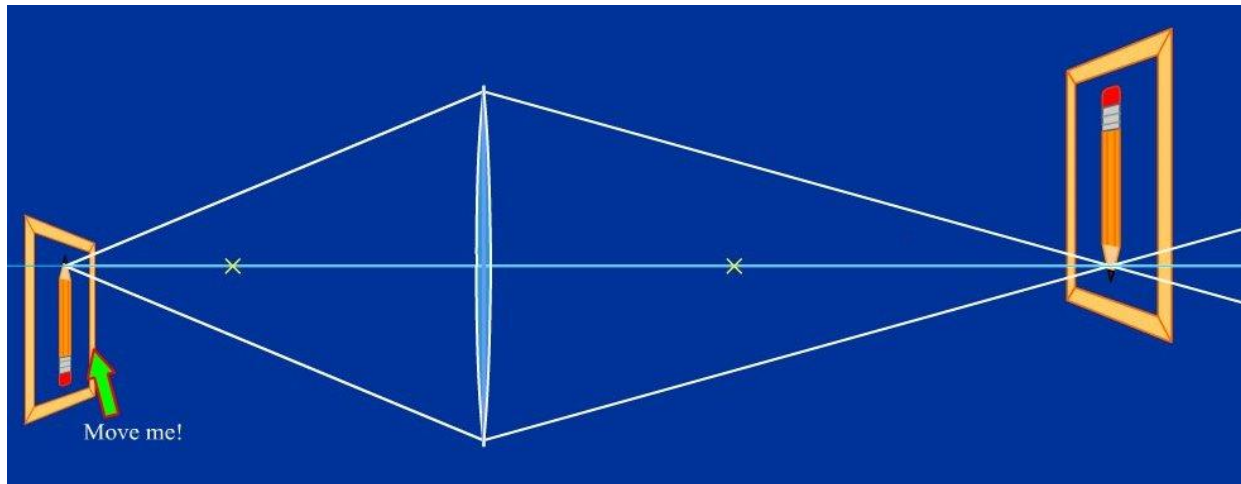
Object height .....

Object distance .....

Image height .....

Image distance.....

**At curvature radius of 0.9 m**



Focal length .....  
Object height .....  
Object distance .....  
Image height .....  
Image distance .....

**B)** Compare the focal length at 0.3 m, 0.6 m and 0.9 m values of the curvature radius and explain in your own words how variations in the curvature radius affect the focal length of a lens.

.....  
.....

5. The characteristics of an image formed by a converging lens do **not** change when the curvature radius of the lens is increased. **True/False?** Explain your answer.

.....  
.....  
.....

## PHYSICS (SHS 2)

### FORMATION OF IMAGES BY A CONVERGING LENS

#### Assignment sheet

Consider a lens system with diameter 0.3 m. If the diameter of the lens was to be replaced by one that is twice the initial diameter with the same focal length with object at the same position. Discuss what will happen to the image formed. Illustrate your answer with ray diagrams.

**Note:** This assignment is to be done in groups and presented in the space provided below.

### D3: PSSPL\_1 ICT intervention by DTA1

#### Lesson plan document

<b>Topic</b>	Reflection and refraction of light from plane and curved surfaces
<b>School level</b>	SHS 1
<b>Subject</b>	Physics
<b>Duration</b>	80minutes (2 periods)
<b>Overview of lesson:</b> In this lesson: reflection and refraction of light, support materials- power point presentation on the lesson- which the teacher uses to introduce the topic and also present summaries of lesson activities; lesson plan, students activity sheet and assignment sheet are provided for effective execution of the lesson. The activities of this lesson are developed based on a PhET simulation entitled bending-light; and are designed in line with lesson objectives and purposed to promote student-centred approach to teaching. Thus, the activity sheet for the lesson is designed to guide students in constructing their own knowledge.	
<b>Specific objectives</b>	At the end of the lesson, students should be able to: <ul style="list-style-type: none"> <li>i. verify the laws of reflection and refraction.</li> <li>ii. determine the refractive index of glass and water using Snell's law.</li> </ul>
<b>Interactive learning objectives</b>	At the end of the lesson, students should be able to use Physics Education Technology (PhET) simulation entitled: bending-light guided by exploratory activities on reflection and refraction of light to: <ul style="list-style-type: none"> <li>i. observe how reflection and refraction takes place.</li> <li>ii. manipulate the various elements of the simulation to identify the angles of incidence, reflection and refraction.</li> <li>iii. compare how the angle of reflection and refraction changes as the angle of incidence is varied.</li> </ul>
<b>Skills</b>	Students will use analytical, critical and observation skills to identify and measure the angle of incidence, reflection and refraction. Students will use their computational skills to find the ratio of the sine of the angle of incidence to the sine of the angle of refraction for different media (e.g. water and glass)
<b>Knowledge</b>	Students will learn to: <ul style="list-style-type: none"> <li>i. explain the laws of reflection and refraction.</li> <li>ii. describe how to determine the refractive index of different media.</li> </ul>
<b>Attitude</b>	<ul style="list-style-type: none"> <li>i. Cooperation: students work together in groups to explore the simulation environment and discuss how the subject matter is represented using the simulation environment.</li> <li>ii. Ingenuity and critical thinking.</li> </ul>
<b>Prerequisite skills and knowledge</b>	Students are able to: <ul style="list-style-type: none"> <li>i. define reflection and refraction in their own words</li> <li>ii. state the laws of reflection and refraction</li> </ul>
<b>Classroom configuration for ICT (simulation) use</b>	Students will form small groups of five in the physics laboratory
<b>Resources</b>	

	<p>ICT: Simulation: PhET Website—bending-light-en (for demonstration, group exploration and discussion) <a href="https://.colorado.edu/edu/sim/bending-light-en/bending-light-en.html">https://.colorado.edu/edu/sim/bending-light-en/bending-light-en.html</a> .</p> <p>PowerPoint presentation software, Projector, computers in the physics laboratory with Google chrome browser installed on it without internet connection.</p> <p>The simulation is downloaded and installed on the computers before the lesson begins</p> <p><b>Other resources:</b></p> <p>Ruler, calculator, pencil, pen, copies of activity sheets for students.</p>	
<p><b>LESSON PLAN</b></p>		
	<p><b>TEACHER ACTIVITY</b></p>	<p><b>STUDENTS'S ACTIVITY</b></p>
<p><b>Introduction</b> (10 minutes)</p>	<p>Teachers introduces the lesson by asking students the following questions:</p> <ol style="list-style-type: none"> <li>i. define reflection, refraction</li> <li>ii. state the laws of reflection and refraction</li> </ol> <p>Teacher uses power point presentation to:</p> <ol style="list-style-type: none"> <li>i. inform students of the lesson outline and objectives.</li> <li>ii. give an overview of the lesson</li> <li>iii. introduce students to the PhET simulation which has been downloaded and installed on the computers.</li> </ol> <p>Teacher asks students to explore simulation for some few minutes</p>	<p>Students answer questions based on their previous knowledge on reflection and refraction</p> <p>Students open the simulation (bending light) on their computer</p> <p>Students explore the PhET simulation environment (bending-light)</p>
<p><b>Main activities</b> (60 minutes)</p>	<p><b>Activity 1:</b> Verification of the laws of reflection (20minutes)</p> <p>In order for students to construct their own knowledge on how to verify the laws of reflection, teacher guides students to do the following in groups:</p> <ul style="list-style-type: none"> <li>➤ Use a snapshot from the simulation environment to help students to setup their simulation for activity one in relation to the simulation</li> </ul>	<p>Based on the snapshot which has been pasted in the activity sheet, students set up the simulation environment as guided by the teacher in order to verify the laws of reflection.</p>

	<p>element such as material, ray and the protractor option</p> <ul style="list-style-type: none"> <li>➤ With the help of the protractor, set the angle of incidence (<math>i^\circ</math>) to <math>10^\circ</math> measure and record the corresponding angle of reflection.</li> <li>➤ Repeat the above step with <math>i^\circ = 20, 30, 40</math> and <math>50</math> and measure the angle of reflection for each value</li> <li>➤ Identify the similarities and differences between the angles of incidence and reflection recorded</li> <li>➤ Briefly explain the observations based on the similarities and differences in the values recorded above.</li> </ul> <p>Teacher then calls a representative from each students group to present their findings for whole class discussion</p> <p>Teacher then summarizes the key physics concepts in activity one, and also presents the solution.</p>	<p>And then answer questions on the activity sheet that fall under activity one based on their prior and newly acquired knowledge.</p> <p>A representative from each group of students presents the solution to the problem for whole class discussion in order to arrive at a consensus.</p> <p><b>Some expected discussion points from students</b></p> <p>The incidence ray, the reflected ray and the normal at the point of incidence (point 'O'), all lie on the same plane.</p> <p>The are no differences in the angles of incidence and the angles of reflection The angle of incidence equals the angle of reflection.</p> <p>Students write down the key physics concept in the activity and may ask questions for further explanation if any.</p>
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	<p><b>Activity 2:</b> Verification of Snell's law (laws of refraction) (30minutes)</p> <p>In order for students to construct their own knowledge on how to verify the laws of refraction, teacher guides students to do the following in groups:</p> <ul style="list-style-type: none"> <li>➤ Use a snapshot from the simulation environment to help students to setup their simulation for activity 2 in relation to the simulation element such as material, ray and the protractor option</li> <li>➤ With the help of the protractor, set the angle of incidence (<math>i^\circ</math>) to <math>10^\circ</math> measure and record the corresponding angle of refraction.</li> <li>➤ Repeat the above step with <math>i^\circ = 20, 30, 40</math> and <math>50</math> and measure the corresponding angles of refraction for each value</li> <li>➤ Compute and record the sine of the angles of incidence and refraction in the activity 2 sheet.</li> <li>➤ Determine the average of the values of <math>\frac{\sin i^\circ}{\sin r^\circ}</math> and state what it represents</li> <li>➤ Based on your interaction with the simulation, briefly outline the steps to follow in determining the refractive index of a glass.</li> </ul> <p>Teacher then calls a representative from each students group to present their findings for whole class discussion</p>	<p>Based on the snapshot which has been pasted in the activity sheet, students set up the simulation environment as guided by the teacher in order to verify the laws of refraction. And then answer questions on the activity sheet that fall under activity 2 based on their prior and newly acquired knowledge.</p> <p>A representative from each group of students presents the solution to the problem for whole class discussion in order to arrive at a consensus.</p> <p><b>Some expected discussion points from students</b></p> <p>The ratio of the sine of the angles of incidence to the sine of the corresponding angles of reflection is a constant.</p> <p>The average of the values of <math>\frac{\sin i^\circ}{\sin r^\circ}</math> is the refractive index of water, thus confirming Snell's law.</p> <p>To determine the refractive index of glass, measure the angle of incidence</p>
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	<p>Teacher then summarizes the key physics concepts in activity 2, and also presents the solution.</p>	<p>and its corresponding angle of refraction. Compute the ratio of the sine of these angles. The obtained value is the refractive index of glass. Students write down the key physics concept in the activity and may ask questions for further explanation if any.</p> <p>Students take notes and then ask questions for more clarification where necessary.</p>
<p><b>Conclusion</b> (10 minutes)</p>	<p>Finally, teacher sums up the whole lesson by highlighting on the key concepts discussed as follows:</p> <p>The laws of reflection and refraction states that:</p> <ol style="list-style-type: none"> <li>1. the incidence ray, the normal and the reflected (or refracted) ray at the point of incidence, all lie in the same plane.</li> <li>2. the angle of incidence equals the angle of reflection (in regular reflections)</li> <li>3. the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant (Snell's law).</li> </ol> <p>Teacher ends the lesson by giving out assignment sheets to students and tell them what the next lesson will be covering</p>	<p>Students take assignment sheets to be worked on at home and returned the next day</p>

## ACTIVITY SHEET

In this activity sheet, you have been provided with 2 activities- Activity 1 and 2. These activities are designed based on the simulation bending-light and are aimed at helping students verify the laws of reflection and refraction, and to help students determine the refractive index of a material using Snell's law

**Note:** all activities are to be done in groups.

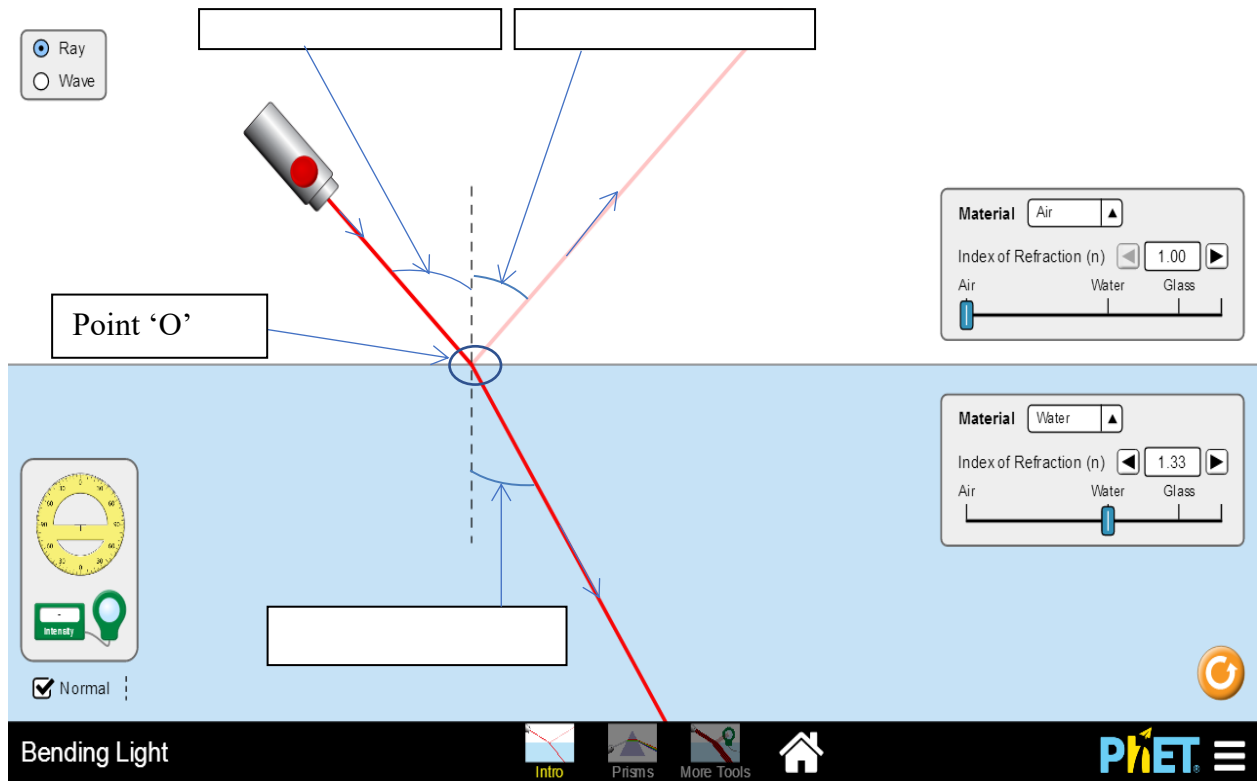
### ACTIVITY 1

Verification of the laws of reflection

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

**Instruction for carrying out the activity**

- Set the simulation environment as shown in the snapshot below  
**Note:** label the parts indicated by boxes in the snapshot below.



- Using your previous knowledge, using the simulation environment, identify the incident ray, the reflected ray and the normal
- With the help of the protractor, set the angle of incidence ( $i^\circ$ ) to  $10^\circ$
- Measure and record the corresponding angle of reflection in the table below
- Repeat the above step with  $i^\circ = 20, 30, 40$  and  $50$  and measure and record the corresponding angle of reflection for each value of  $i^\circ$

Incident angle	$10^\circ$	$20^\circ$	$30^\circ$	$40^\circ$	$50^\circ$
Reflected angle					

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

.....

.....

- Identify the similarities and differences (if any) between the angles of incidence and their corresponding angles of reflection recorded

.....  
 .....

- From your observation and simulation environment, was the 2<sup>nd</sup> law of reflection verified?

.....  
 .....

## ACTIVITY 2

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

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

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

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

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

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

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

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

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3. The refractive index for water is stated as being 1.33 from the simulation environment. Compare this to the value you obtained in question 2 above, what do you notice?

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4. Is there any difference between the values you stated above? If so come up with possible reasons as to how this could have occurred.

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5. Based on your interaction with the simulation, briefly outline the steps to follow in determining the refractive index of a glass.

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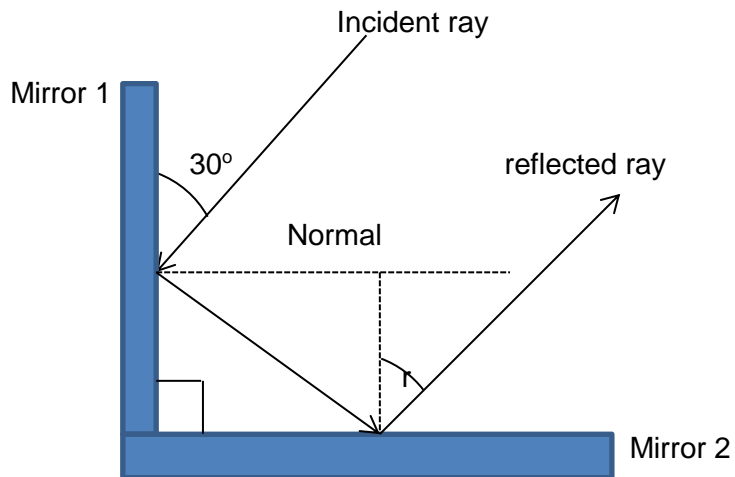
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**Real life application**

1. A ray of light incident at an angle in air to the surface of glass is reflected at an angle of  $60^\circ$ . Find the angle of refraction the refractive index of glass from the simulation environment (show working).

## Assignment sheet

1. Find the angle  $r$  in the diagram below.



2. Distinguish between reflection and refraction

#### D4: PSSPL\_2 ICT intervention by DTB1

##### Lesson plan document

<b>TOPIC</b>	Atomic and Nuclear physics
<b>SUB TOPIC</b>	Structure of the atom
<b>CLASS</b>	2Sci 1
<b>SUBJECT</b>	Physics
<b>DURATION</b>	80 minutes
<b><u>OVERVIEW OF LESSON:</u></b> In this lesson, we will look at the structure of the atom where teacher uses PowerPoint presentation to introduce the lesson, direct the main activity and summaries the core points of the lesson. PhET (Physics Education Technology) simulation entitled: <b>Build an Atom</b> is the core ICT tool used in developing the activities of the lesson. Lesson plan, students' activity sheet and assignment sheet are designed based on the simulation and the objectives of the lesson. Students' worksheets are designed in order to guide students construct their own knowledge as they interact with the simulation environment. The aim of this lesson is to guide students to familiarize themselves with the properties of atom and the periodic table so as to better understand the various models of the atom.	
<b>SPECIFIC OBJECTIVES</b>	At the end of the lesson, students should be able to identify: <ol style="list-style-type: none"><li>1. element on the periodic table.</li><li>2. symbol of the element.</li><li>3. group and period of the element.</li><li>4. net charge of the element.</li><li>5. mass number of the element.</li></ol>
<b>INTERACTIVE LEARNING OBJECTIVES</b>	At the end of the lesson, students should be able to use Physics Education Technology (PhET) simulation entitled: <b>Build an Atom</b> guided by exploratory activities on the structure of an atom to <ol style="list-style-type: none"><li>1. identify the various element on the periodic table by varying the number of protons.</li><li>2. Verify the effect of protons and electrons on the net charge readings.</li><li>3. Identify the group and period of metals, metalloids, non-metals and rare/ inert gases.</li></ol>
<b>SKILL</b>	Students need deductive, critical thinking, analytical and observational skills to identify the various elements and classify them as metals, metalloids, non-metals and rare/ inert gases.

<b>KNOWLEDGE</b>	<p>Students will learn to:</p> <ol style="list-style-type: none"> <li>1. Identify elements using the number of protons.</li> <li>2. Verify the net charge on an atom using the number of protons and electrons.</li> <li>3. Classify elements into metals, metalloids, non-metals and rare/inert gases.</li> </ol>
<b>ATTITUDE</b>	<ol style="list-style-type: none"> <li>1. Deductive reasoning and critical thinking.</li> <li>2. Collaboration: Students will be working in groups using the simulation environment and other activities. (Students activity)</li> </ol>
<b>PREVIOUS KNOWLEDGE</b>	<p>Students have been taught to:</p> <ol style="list-style-type: none"> <li>1. define an atom in their own words.</li> <li>2. state the sub-atomic particles.</li> <li>3. draw the atom and identify the sub-atomic particles.</li> </ol>
<b>CLASSROOM CONFIGURATION FOR ICT (SIMULATION)USE</b>	<p>Students are grouped into five with four members in each group. Each group is provided with a computer.</p>
<b>RESOURCE</b>	<ol style="list-style-type: none"> <li>1. Presentation (PowerPoint)</li> <li>2. Projector</li> <li>3. <i>The Teaching Syllabus for Physics for Senior High Schools by CRDD, 2010.</i></li> <li>4. Simulation: PhET website- <b>builds an atom</b> (to be used for both demonstration and exploration).</li> <li>5. Worksheet (printed copy will be given to the students during the course of the lesson)</li> <li>6. Computers (without internet)</li> <li>7. Lesson Plan</li> </ol> <p><b>NOTE:</b> Teacher downloads simulation on the structure of an atom on his computer and five other computers. In case there is no internet, the computers can be used. Teacher prints students' worksheet and the periodic table.</p> <p><b>Other resources:</b> periodic table, pencil, eraser and paper.</p>

LESSON PLAN		STUDENT ACTIVITY
TEACHER ACTIVITY		STUDENT ACTIVITY
<p><b><u>Introduction</u></b> Review of Students' previous knowledge (15minutes)</p>	<p>Teacher gives each group of students review question sheet on which they are to:</p> <ul style="list-style-type: none"> <li>• Circle the true statement about an atom</li> <li>• Identify the sub-atomic particles based on the description that best fit the particle.</li> <li>• To draw the structure of an atom.</li> </ul> <p>Teacher then asks one of the students to draw the atomic structure on the board after which the class discusses.</p> <p>Teacher commends on Students' responses.</p> <p>Teacher draws students' attention to the lesson outline and the resources projected from his laptop computer using LCD projector.</p>	<p>Students follow the instructions on the review question sheet to answer the questions in groups.</p> <p><b><u>Expected answers from the students</u></b></p> <p>C. Atom is the smallest particle into which an element can be divided without losing its chemical properties.</p> <p>A. Electron B. Neutron C. Proton</p> <div style="text-align: center;"> <p>key e = electron n = neutron p = proton</p> </div> <p>Students contribute to the discussion.</p> <p>Students pay attention and take note of the lesson outline and resources.</p>

	<p>Teacher then connects students' responses to the content and shares lesson objectives with the students.</p>																	
<p><b><u>Content Development</u></b>  <b>(50minutes)</b></p>	<p><b><u>Activity 1</u></b>          In this activity, teacher guides students to identify the element, its symbol, period and group using the simulation environment.          Teacher draws Students' attention to the simulation and asks them to interact with the simulation in group for five minutes.          Teacher then draws students' attention to the screenshot of the simulation and asks them to:</p> <ul style="list-style-type: none"> <li>• Set the simulation environment according to the screenshot.</li> <li>• Place the cursor on protons and drag into the atom each at a time.</li> <li>• Identify the element, its symbol, period and group as they add the proton(s) in group.</li> </ul>	<p>Students interact with the simulation environment and discuss among themselves as they explore the simulation.</p> <p>Students follow the instructions on their worksheet and answer the questions in activity 1 in groups.</p> <p><b><u>Some expected answers from the students</u></b>  <b><u>ELEMENTS</u></b>  <b><u>SYMBOLS</u></b></p> <table style="width: 100%; border: none;"> <tr> <td>Hydrogen</td> <td style="text-align: right;">H</td> </tr> <tr> <td>Helium</td> <td style="text-align: right;">He</td> </tr> <tr> <td>Lithium</td> <td style="text-align: right;">Li</td> </tr> <tr> <td>Beryllium</td> <td style="text-align: right;">Be</td> </tr> <tr> <td>Boron</td> <td style="text-align: right;">B</td> </tr> <tr> <td>Carbon</td> <td style="text-align: right;">C</td> </tr> <tr> <td>Nitrogen</td> <td style="text-align: right;">N</td> </tr> <tr> <td>Oxygen</td> <td style="text-align: right;">O</td> </tr> </table>	Hydrogen	H	Helium	He	Lithium	Li	Beryllium	Be	Boron	B	Carbon	C	Nitrogen	N	Oxygen	O
Hydrogen	H																	
Helium	He																	
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	<p>Teacher briefly discusses activity 1 and then summaries expected answers of the activity 1.</p> <p><b><u>Activity 2</u></b>  In this activity, teacher guides students to find out the mass number and the net charge of element. Teacher guides students to do the following in groups.</p> <ul style="list-style-type: none"> <li>• Close the simulation and reopen it.</li> <li>• On the net charge and mass number bar which is below the element bar, click on the positive sign to change to negative sign.</li> <li>• Use the protons (p) and neutrons (n) to find the mass number of each element by dragging one proton and one neutron at a time.</li> </ul> <p>Teacher discusses the questions on the activity 2 and briefly highlights on the key points.</p> <p><b><u>Activity 3</u></b>  In this activity teacher guides students to classify the elements into metals, metalloids, non-metals and rare/Inert gases by using the simulation. Teacher guides students to do the following in groups.</p> <ul style="list-style-type: none"> <li>• Close the simulation and reopen it.</li> <li>• Add one proton to the atom and note the group of the element that appears on the periodic table.</li> </ul>	<p>Fluorine F  Neon Ne</p> <p>Students contribute to the discussion and take note of the expected answers.</p> <p>Students explore the simulation environment by following the instructions on the worksheet to answer the questions on activity 2 in groups.</p> <p>Students contribute to the discussion and write down the key points.</p> <p>Students explore the simulation by following the instruction on the worksheet as well as using their prior (new) knowledge constructed in activity 1 to answer the questions on activity 3 in groups.</p>
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	<ul style="list-style-type: none"> <li>Carefully observe the position of the elements as more protons are added.</li> <li>Repeat step 1 and 2 but for the following number of protons: 2, 3, 4, 5, 6, 7, 8, 9, and 10.</li> <li>Classify the elements into metals, metalloids, non-metals and rare/inert gases.</li> </ul> <p>Teacher asks two groups to present their answers on the board after which they brainstorm. Teacher commends on Students responses and highlights on the main points.</p>	<p><b><u>Some expected answers from the students</u></b>  <b>Metals:</b> Hydrogen, Lithium, Beryllium, Boron  <b>Metalloids:</b> Carbon  <b>Non-Metals:</b> Nitrogen, Fluorine, Oxygen  <b>Rare/inert:</b> Helium, Neon.</p> <p>Students pay attention as the groups present their work after which they brainstorm.</p> <p>Students take note of the main points.</p>												
<p><b>Conclusion</b> <b>(15minutes)</b></p>	<p>Teacher reviews the lesson by asking the question below:</p> <ol style="list-style-type: none"> <li>Identify the element, symbol, group, period, net charge and mass number of an element with 8 protons and 3 neutrons.</li> </ol>	<p>Students provided the question answer as follows:  Element---Oxygen,  Group----6,  Period-----2,  Net charge-----+8,  Mass number-----11</p>												
	<p>Teacher then summarizes the lesson by highlighting on the main points:</p> <p><b>Activity 1</b></p> <table border="0"> <thead> <tr> <th><u>ELEMENTS</u></th> <th><u>SYMBOLS</u></th> </tr> </thead> <tbody> <tr> <td>Hydrogen</td> <td>H</td> </tr> <tr> <td>Helium</td> <td>He</td> </tr> <tr> <td>Lithium</td> <td>Li</td> </tr> <tr> <td>Beryllium</td> <td>Be</td> </tr> <tr> <td>Boron</td> <td>B</td> </tr> </tbody> </table>	<u>ELEMENTS</u>	<u>SYMBOLS</u>	Hydrogen	H	Helium	He	Lithium	Li	Beryllium	Be	Boron	B	<p>Students ask questions for clarification and write down note.</p>
<u>ELEMENTS</u>	<u>SYMBOLS</u>													
Hydrogen	H													
Helium	He													
Lithium	Li													
Beryllium	Be													
Boron	B													

Carbon C  
 Nitrogen N  
 Oxygen O  
 Fluorine F  
 Neon Ne

**Activity 2**

Element	P+N	Net Charge
Helium	4	+2
Beryllium	8	+4
Carbon	12	+6
Nitrogen	14	+7
Neon	20	+10

13. As more protons are added, the mass number and the net charge reading also increase.  
 14. As more electrons are added, the net charge reading decrease or reduces.

**Activity 3**

**Metals:** Hydrogen, Lithium  
 Beryllium, Boron  
**Metalloids:** Carbon  
**Non-Metals:** Nitrogen, Fluorine  
 Oxygen  
**Rare/inert:** Helium, Neon

24. The net charge on fluorine is +3.  
 25. Group is the vertical (column) arrangement of the elements on the periodic table whereas period is the horizontal(row) arrangement of the elements on the periodic table  
 Teacher gives assignment sheet to Students and also asks them to read on stability and instability of element for the next lesson.

Students take the assignment sheet and write down the reading assignment.

ACTIVITY SHEETS

**REVIEW QUESTIONS ON STUDENTS PREVIOUS KNOWLEDGE**

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

DURATION: 15 minutes

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

## Physics: Atomic and Nuclear Physics Student Activity

GROUP MEMBERS NAMES:

DURATION: 30 minutes.

Purpose: In all the three activities in this worksheet, at the end of the activity; Students should be able to identify element on the periodic table, its symbol, group, period, net charge and mass number.

Background Information: This worksheet is made up of three **activities**: **Activity 1** involves identification of elements, their symbols, periods and groups. **Activity 2** deals with net charge and mass number of each element and **Activity 3** consists of practical applications of groups of elements to classify them as metals, metalloids, non-metals and rare gases. **NOTE**: All these activities are to be done in group using the simulation.

### ACTIVITY 1

**Instruction:**

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

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

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

**Fill in the blank spaces**

**In the simulation environment;**

- Place the cursor on protons and drag into the atom each at a time.
- Identify the element, its symbol, period and group as you add the proton(s).

1. Element with one proton    2. Element with two protons    3. Element with three protons

Element name \_\_\_\_\_

Symbol \_\_\_\_\_

period \_\_\_\_\_

Group \_\_\_\_\_

Element name \_\_\_\_\_

Symbol \_\_\_\_\_

Period \_\_\_\_\_

Group \_\_\_\_\_

Element name \_\_\_\_\_

Symbol \_\_\_\_\_

Period \_\_\_\_\_

Group \_\_\_\_\_

4. Element with four protons  
protons

Element Name \_\_\_\_\_

\_\_\_\_\_

Symbol \_\_\_\_\_

Period \_\_\_\_\_

Group \_\_\_\_\_

5. Element with five protons

Element Name \_\_\_\_\_

Symbol \_\_\_\_\_

Period \_\_\_\_\_

Group \_\_\_\_\_

6. Element with six

Element Name \_\_\_\_\_

Symbol \_\_\_\_\_

Period \_\_\_\_\_

Group \_\_\_\_\_

## ACTIVITY 1 SCREENSHOT

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

SCREENSHOT 'A'

## ACTIVITY 2

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

In the simulation environment;

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

Use the number of protons to verify the elements.

ELEMENT	PROTON(P)	NEUTRON(N)	P+N	NET CHARGE
7. Helium	_____	_____ 2 _____	_____	_____
8. Beryllium	_____	_____ 4 _____	_____	_____

9. Carbon	_____	<u>6</u>	_____	_____
10. Nitrogen	_____	<u>7</u>	_____	_____
11. Neon	_____	<u>10</u>	_____	_____

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

.....  
 .....  
 .....

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

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

.....  
 .....

### ACTIVITY 3

Instruction:

In the simulation environment;

- Close the simulation and reopen it.
- Add one proton to the atom and note the group of the element that appears on the periodic table.
- Carefully observe the position of Hydrogen, Helium, Lithium, Beryllium, Boron, Carbon, Nitrogen, Oxygen, Fluorine, and Neon as more protons are added.
- Repeat step 1 and 2 but for the following number of protons: 2, 3, 4, 5, 6, 7, 8, 9, and 10.
- Classify the elements into metals, metalloids, non-metals and rare/Inert gases.

METALS	METALLOIDS	NON-METALS	RARE GASES
14 _____	15 _____	16 _____	17 _____
18 _____		19 _____	20 _____
21 _____		22 _____	

**NOTE:** Set the simulation environment as it is on the screenshot before answering question 24.

24. What is the net charge on Fluorine when 6 electrons are added to the atom?

25. What is the difference between group and period of element on the periodic table? \_\_\_\_\_

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### ASSIGNMENT SHEET

From your new knowledge acquired on the simulation environment, use the periodic table to reclassify the following elements under metals, metalloids, non-metals and rare/inert gases.

METALS	METALLOIDS	NON-METALS	RARE/INERT GASES
Calcium	Aluminum	Germanium	Xenon
Helium	Silicon	Oxygen	Sodium
Argon	Carbon	Chlorine	Neon
Potassium	Sulphur	Indium	Phosphorus

Reclassify the elements in the table and complete the table below.

METALS	METALLOIDS	NON-METALS	RARE/INERT GASES

#### D4: PSSPL\_3 ICT intervention by DTA2

##### Lesson plan document

<b>SUBJECT</b>	Physics	<b>SCHOOL LEVEL</b>	SHS 3
<b>TOPIC</b>	Mechanics	<b>TIME</b>	11.00am-12.20pm
<b>SUB-TOPIC</b>	Deformation of solids	<b>DURATION</b>	80minutes
<p><b>OVERVIEW OF LESSON:</b> In this lesson, the following support materials are developed for effective execution of the lesson: 1) Power Point Slides-which the teacher would use to introduce the topic and also present summaries of lesson activities; 2) Lesson plan- which shows a step by step organization of the lesson to be conducted; 3) Student activity sheet and 4) Assignment sheet. The activities for this lesson are developed based on a Physics Education Technology (PhET) simulation entitled: <i>Hooke's Law</i>; and are designed in line with the lesson objectives and purposed to promote student-centred approach to teaching. Thus, the activity sheet for the lesson is designed to guide students in constructing their own knowledge.</p>			
<b>Specific Objectives</b>	<p>By the end of this lesson, students will be able to:</p> <ul style="list-style-type: none"> <li>❖ explain the behavior of elastic material (spring) under stress.</li> <li>❖ discuss how applied force influences displacement.</li> </ul>		
<b>Interactive Learning Objectives</b>	<p>By the end of this lesson, students will be able to use and explore Physics Education Technology (PhET) simulation entitled: <i>Hooke's Law</i> to:</p> <ul style="list-style-type: none"> <li>❖ observe how a spring behaves when: <ul style="list-style-type: none"> <li>✓ applied force value is changed.</li> <li>✓ spring constant value is varied.</li> </ul> </li> <li>❖ compare how applied force values affects displacement and spring constant values.</li> </ul>		
<b>Skills</b>	<p>Students will develop their analytical, critical and observation skills to:</p> <ul style="list-style-type: none"> <li>❖ explain the behavior of spring under stress.</li> <li>❖ describe how applied force influences displacement.</li> </ul>		
<b>Knowledge</b>	<p>Students will learn:</p> <ul style="list-style-type: none"> <li>❖ about the types of forces that produce deformation.</li> <li>❖ to describe how applied force affects displacement and spring constant in their own words.</li> <li>❖ identify applications of Hooke's Law.</li> </ul>		
<b>Attitude</b>	<p>Creative and critical thinking. Collaboration: students to work together in groups to explore and interact with the simulation environment as the teacher demonstrates and then, discuss how well the subject matter is represented using the simulation environment.</p>		
<b>Prerequisite Skills and Knowledge</b>	<p>Students are able to:</p> <ul style="list-style-type: none"> <li>❖ identify elastic materials (spring)</li> <li>❖ explain the opposition by a spring force in trying to insert a battery into a torch.</li> <li>❖ write a mathematical equation between two variables.</li> </ul>		
<b>Classroom Configuration for ICT (Simulation) Use</b>	<p>A group of students (maximum of sixteen students) in classroom</p>		
<b>Resources</b>	<p>ICT:</p>		

	<ul style="list-style-type: none"> <li>❖ Simulations: PhET website - Hooke's Law (for demonstration) <a href="https://phet.colorado.edu/en/sims/Hookees-law.html">https://phet.colorado.edu/en/sims/Hookees-law.html</a></li> <li>❖ Presentation software (Microsoft PowerPoint)</li> <li>❖ Projector</li> </ul> <p><b>NB:</b> This lesson has been designed to fit the classroom situation where there is no internet and only the teacher has access to a computer, thus, the teacher downloads the simulations onto available computer prior to the lesson execution, to be used offline in the classroom for demonstration. The lesson can be adapted in situations where there is access to internet and a computer laboratory/classroom with computers for students.</p> <p><b>Other resources:</b> pencil and copies of activity/assignment sheet</p>	
<b>Lesson Plan</b>		
Stage, Step, Content Item, Estimated Time	Teacher Activity	Student Activity
Introduction (15 minutes)	<p>Teacher displays a picture that is associated with deformation of springs, and asks students to:</p> <ul style="list-style-type: none"> <li>❖ identify what tool it is.</li> <li>❖ describe what happens to the tool when they try to put battery inside a torch.</li> </ul> <p>Teacher calls students at random to write their answers on the board and he proceeds to comment on the answers.</p> <p>Teacher uses the previous knowledge of the students to introduce the topic of the day.</p> <p>Teacher presents some test items (pre-test) on</p>	<p>Students observe the picture presented, discuss, share ideas and write the answer on the board when called by the teacher to do so.</p> <p><u>Expected responses from students</u></p> <ul style="list-style-type: none"> <li>❖ a. spring b. wire</li> <li>❖ A. the spring compresses B. the spring becomes difficult to press C. the spring pushes the battery</li> </ul> <p>Students listen and write the topic of the lesson into their notebooks.</p>

	<p>deformation of solids to students at the beginning of the lesson.</p> <p>By the use of Microsoft PowerPoint presentation software, teacher:</p> <ul style="list-style-type: none"> <li>❖ outlines lesson objectives to students.</li> <li>❖ gives an overview of the lesson, placing emphases on how the demonstration aspect of the lesson will be done.</li> <li>❖ explains the group arrangement for the lesson to students.</li> <li>❖ introduces students to the PhET simulation (entitled <i>Hooke's Law</i>) environment employed for lesson.</li> <li>❖ gives an overview of the lesson activities and how each activity sheet will be executed.</li> </ul> <p>Teacher projects the simulation on the board and allows students to observe and make sense of the interactive features of the simulations for about 5 minutes.</p> <p>Teacher guides students to answer the questions on the introductory activity sheet under <i>introductory activity2</i> (in groups) after observing and making sense of the simulation environment based on their prior knowledge on deformation of elastic materials.</p> <p>Teacher guides students to summarize <i>introductory</i></p>	<p>Students answer the test items based on their prior knowledge on deformation of solids.</p> <p>Student's discuss, in groups, the interactive features of the simulation environment and then brainstorm to make predictions about the functions of the features they observe based on their prior knowledge on elastic materials.</p> <p>Students work in groups to answer the questions on the introductory activity sheet (under <i>introductory activity2</i>) based on their prior knowledge on deformation of elastic materials.</p>
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	<p><i>activity</i> by calling each group representative to demonstrate the group predictions about the features of the simulation in relation to deformation of solids to the class.</p> <p>Teacher ends introductory session with a detailed demonstration of how each feature in the simulation environment functions to enable the deformation of the spring.</p>	<p>Students ask questions about each group's predictions on the aspects of deformation the simulation mimics and came to a consensus about the proper roles of the simulation elements.</p> <p>Students fill in the gaps in their constructed knowledge about deformation of springs by matching their group findings to the teacher's demonstrations. Students also ask questions where necessary to get better understanding of the key physics concepts.</p>
<p><b>Main Activities</b> (new knowledge, reinforcements, and reflections)</p>	<p><b>Activity 1:</b> Explanation of the behavior of elastic material (spring) under stress (25 minutes).</p> <p>In this activity, the teacher guides students by the use of the PhET simulation (through demonstration and activity sheet) to help students construct their own knowledge.</p> <p>In particular, teacher guides students to do the following:</p> <ul style="list-style-type: none"> <li>❖ observe, identify and describe the behavior of the spring as the slide button of the applied force is moved from: <ul style="list-style-type: none"> <li>a. default to 100N</li> <li>b. 100N to -100N</li> </ul> </li> <li>❖ describe the behavior of the spring as he moves the spring constant slide from: <ul style="list-style-type: none"> <li>a. default to 1000N/m</li> <li>b. 1000N/m to 100N/m</li> </ul> </li> </ul>	<p>Students will observe, discuss (in groups) and make sense of the demonstrations made by the teacher or their colleague student using the simulations, and then answer the questions under <i>activity 1</i> (on the activity sheet) based on their observations and newly acquired knowledge.</p>

	<p>After activity 1, teacher asks each group to share their observations and findings with the whole class for discussion.</p> <p>Teacher then projects summarizes of the key physics concepts in the activity 1.</p> <p><b>Activity 2:</b> How applied force influences displacement (25minutes).</p> <p>This activity is geared towards investigating Hooke's Law using the PhET simulation – <i>Hooke's Law</i>. By setting the simulation environment such that the boxes in the <i>indicator column</i> beside values, applied force, spring force, displacement and equilibrium were marked, and spring constant value is kept at constant value of 100N/m, teacher guides students through demonstration to do the following in groups:</p> <ul style="list-style-type: none"> <li>❖ observe the values of the displacement and spring constant in relation to how they both equal to spring force, in order to define</li> </ul>	<p>Students share ideas by discussing their answers to the questions under activity 1 with their colleagues to finally come to a consensus about the spring behavior as spring constant and applied force values are varied as demonstrated by the teacher.</p> <p><u>Expected responses from students</u></p> <ul style="list-style-type: none"> <li>❖ A. The spring compresses as applied force moves towards -100N B. The spring stretches as applied force moves towards 100N.</li> <li>❖ A. The spring compresses as spring constant moves towards -100N/m. B. The spring stretches as spring constant moves towards 1000N/m.</li> </ul> <p>Students copy key points into their notebooks from the presentation the teacher projects on the board.</p> <p>Students observe teacher or colleague student as he/she explores the simulations through demonstration with respect to the outlined guidelines by the teacher in order to define spring force; write an equation for both forces; predict how applied force affects displacement but differs from spring force; and then show mathematically the relationship between applied force, spring</p>
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	<p>spring force in their own words mathematically (in <i>activity 2</i> on activity sheet), when applied force value is set at:</p> <ul style="list-style-type: none"> <li>• 50N</li> <li>• 100N</li> </ul> <ul style="list-style-type: none"> <li>❖ observe and compare the values of applied force to spring force in order to write an equation for both forces (as answer to question under <i>activity 2</i> on the activity sheet) when the applied force value is altered using the applied force slider.</li> <li>❖ predict, based on observation, how the applied force: <ul style="list-style-type: none"> <li>a. affects the displacement.</li> <li>b. differs from the spring force.</li> </ul> </li> <li>❖ write a mathematical equation relating applied force (F) to displacement (X) and spring constant (K) taking into consideration the direction of the spring force as opposed to applied force.</li> </ul> <p>After <i>activity 2</i>, teacher asks each group to share with the whole class for discussion their finding on how applied force relates to displacement and spring constant mathematically considering the direction of both forces.</p>	<p>constant and displacement as well as answer the questions under <i>activity 2</i> on the activity sheet based on prior as well as newly acquired knowledge and experiences with the simulation environment.</p> <p>Students share ideas by discussing their answers to the questions under <i>activity 2</i> with their colleagues to finally come to a consensus on how applied force affects displacement and spring constant, and how different spring force is to applied force.</p>
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	<p>The teacher summarizes the core points in <i>activity 2</i>.</p>	<p><b>Some expected discussion points include:</b></p> <p>❖</p> <table border="1"> <thead> <tr> <th>Applied force</th> <th>Spring constant</th> <th>displacement</th> <th>spring force</th> </tr> </thead> <tbody> <tr> <td>50N</td> <td>100N/m</td> <td>0.500m</td> <td>50N</td> </tr> <tr> <td>100N</td> <td>100N/m</td> <td>1.000m</td> <td>100N</td> </tr> </tbody> </table> <p>Thus, spring force= spring constant X displacement.</p> <ul style="list-style-type: none"> <li>❖ Spring force is dependent on applied force/ spring force increases as applied force increases and vice versa/spring force value is equal to applied force value. Thus, applied force=spring force</li> <li>❖ a. Displacement is directly proportional to applied force/displacement changes with respect to applied force. b. applied force is in opposite direction to spring force.</li> <li>❖ Since applied force is in opposing direction to spring force (spring constant times displacement), it implies that <math>F=-kX</math></li> </ul> <p>Students copy key points into their notebooks from the presentation the teacher projects on the board and then ask questions where necessary for better understanding.</p>	Applied force	Spring constant	displacement	spring force	50N	100N/m	0.500m	50N	100N	100N/m	1.000m	100N
Applied force	Spring constant	displacement	spring force											
50N	100N/m	0.500m	50N											
100N	100N/m	1.000m	100N											
<p><b>Conclusion</b> (15minutes)</p>	<p>Teacher guides students to discuss some applications of deformation of solids (spring) by asking them about how the concept of spring deformation is being applied in daily life.</p> <p>Also, the teacher sums up the lesson by showing a short video clip on deformation of spring (saved offline). <a href="https://youtu.be/x8_ExQrgvsQ">https://youtu.be/x8_ExQrgvsQ</a></p> <p>Teacher, then ends the lesson by giving out:</p>	<p>Students share their experiences with the class for a brief discussion.</p> <p>Students take notes and ask questions for clarification where necessary.</p>												

	<ul style="list-style-type: none"> <li>❖ the same test items given to them in the beginning of the lesson for them to redo.</li> <li>❖ assignment sheets to students.</li> </ul>	<ul style="list-style-type: none"> <li>❖ Students redo the test as a way of assessing themselves on the physics concept discussed during the lesson.</li> <li>❖ Students take assignments sheet to be solved as homework.</li> </ul>
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**INTRODUCTORY ACTIVITY SHEET**

PHYSICS (SHS 3)

**Deformation of Solids**

Name: .....

**Introductory Activity 1 (Pre/post-test).**

1. Indicate whether the following statements are **true** or **false**.
  - Spring is an elastic material. **True/False**
  
  - Spring exerts a force on the object that is attached to it, in order to restore its shape. **True/False**
  
2. Length of a spring during it's relax state is called .....

.....

3. If  $K$  is spring constant,  $X$  is deformation length, and  $F$  is applied force, then Hooke's Law can be written mathematically as .....
  
4. What is another name for spring force?

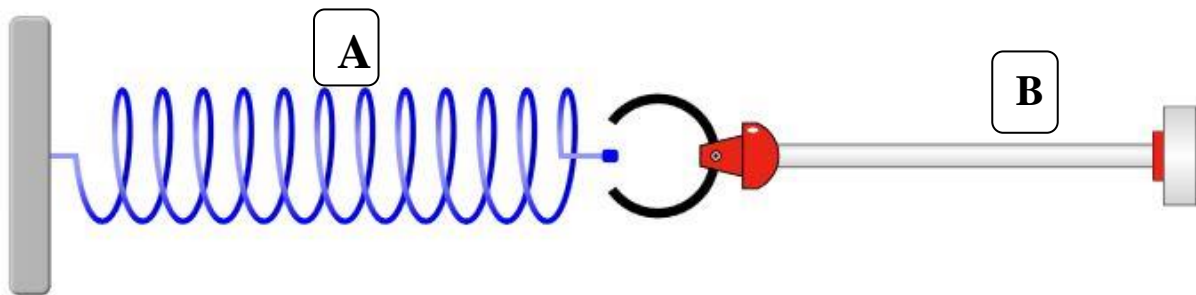
Ans.....

## Introductory Activity 2

The images below are snapshots of some of the elements from the simulation projected on the board. This activity would guide you to:

- identify and make predictions about how each of the elements in the PhET simulation entitled “*Hooke’s Law*” based on your prior knowledge.
- discuss and answer the questions in this activity in groups

1. By observing the simulation environment, fill in the table below by predicting the functions of each of the elements labelled with regards to the simulation environment.



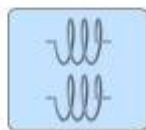
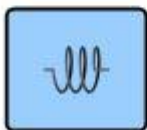
C

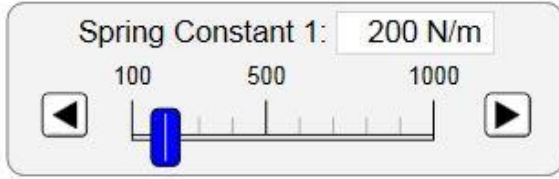
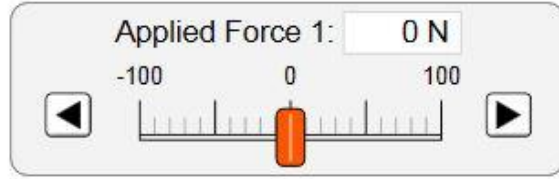


D

<input type="checkbox"/>	Applied Force	
<input type="checkbox"/>	Spring Force	
<input type="checkbox"/>	Displacement	
<input type="checkbox"/>	Equilibrium Position	
<input type="checkbox"/>	Values	

E



**F****G**

Label of Element in Simulation	Purpose it serves in the simulation environment
A	
B	
C	
D	
E	
F	
G	

**ACTIVITY SHEET**

PHYSICS

**Deformation of Solids**

Group Name: .....

**INTRODUCTION**

This activity sheet comprises of two activities – **activity 1** and **activity 2**. These activities are developed based on a simulation on deformation – *Hooke’s Law* and are purposed to help you explain how a spring behave under stress and Hooke’s Law. All activities should be done in group.

**Activity 1:** Explanation of the behavior of elastic material (spring) under stress.

This activity is aimed at explaining the behavior of spring under stress.

Based on your observation of the demonstration exercises using the simulation, discuss in groups to answer the questions below.

Q1. Describe the behavior of the spring as the

a. slide button of the applied force is moved from:

ii. default to 100N

.....

iii. 100N to -100N

.....

b. spring constant slide is moved from:

c.

i. default to 1000N/m

.....

ii. 1000N/m to 100N/m

.....

**Activity 2:** How applied force influences displacement.

In this activity, you will be verifying Hooke's Law.

Per your observation of the demonstration exercises using the simulation, discuss in groups to answer the questions below:

1. By observing the demonstration, complete the table below with the required values.

Applied force	Spring constant (K)	Displacement (X)	Spring force (F)
50N			
100N			

Compare the values in the table above and write an equation relating the spring force(F), displacement(X) and the spring constant(K).

.....

2. In simple terms, compare the values of both **applied force** and **spring force** based on your observation and write an equation for them.

.....  
.....  
.....

3. Based on your observation of the demonstration, discuss how the applied force:

a. affects the displacement.

.....  
.....

b. differs from the spring force.

.....  
.....

4. Write a mathematical equation relating applied force (F) to displacement(X) and spring constant (K) taking into consideration the direction of the spring force as opposed to applied force. ....

PHYSICS (SHS 3)

**Deformation of Solids**

Assignment sheet

Group Name: .....

1. Explain stress.
2. Calculate the spring constant of a helical spring stretched by a load of mass 50kg at acceleration of  $10\text{m/s}^2$  through a distance of 5m.
3. State Hooke's law.

## D5: PSSPL\_4 ICT intervention by DTAB2

### Lesson plan document

<b>Subject</b>	Physics	<b>School level</b>	SHS 2
<b>Topic</b>	Forces	<b>Duration</b>	80 minutes
<b>Sub Topic</b>	Frictional Force	<b>Class Size</b>	18
<b>Date</b>	27/09/2017		
<p><b>Overview of Lesson:</b> This lesson is actualized and made effective through the following teaching and learning resources:</p> <ol style="list-style-type: none"> <li>1. Power point: The teacher will use to commence the topic, guide students in their activities and present summaries of the lesson.</li> <li>2. Lesson plan: This depicts a systematic arrangement of the lesson to be taught.</li> <li>3. Student activity sheet</li> <li>4. Assignment sheet: The activities for this lesson are developed based on a PhET simulation captioned: Forces and Motion: Basics (Friction) are prepared based on the lesson objectives to promote student-centered approach to teaching. The activity sheet for the lesson will guide students to come out with their own knowledge.</li> </ol>			
<b>Specific objectives</b>	<p>By the end of the lesson, the student should be able to:</p> <ul style="list-style-type: none"> <li>➤ define frictional force</li> <li>➤ state at least two effects of frictional force on moving objects</li> </ul>		
<b>Interactive lesson objectives</b>	<p>At the end of the lesson, students will be able to use the Physics Education Technology (PhET) simulation captioned: Forces and Motion: Basics (Friction) guided by exploratory activities on Forces and Motion to:</p> <ul style="list-style-type: none"> <li>➤ observe how friction opposes the motion of a moving body</li> <li>➤ manipulate the various elements of the simulation to explain the effects of friction</li> </ul>		
<b>Skills</b>	<p>Students will use analytical, inferential, critical and observation skills to explain the effects frictional force.</p>		
<b>Knowledge</b>	<p>Students will learn to:</p> <ul style="list-style-type: none"> <li>➤ define frictional force in their own words</li> <li>➤ explain the effects of frictional force</li> <li>➤ apply these in their daily life</li> </ul>		
<b>Attitude</b>	<ul style="list-style-type: none"> <li>• Co-operation: Students to work together in groups in exploring the simulation environment and then discuss how well the subject matter is represented using the simulation environment.</li> <li>• Creativity and critical thinking.</li> </ul>		
<b>Prerequisite skills and knowledge</b>	<p>Students have been taught in their previous lessons:</p> <ol style="list-style-type: none"> <li>1. forces</li> <li>2. types of forces</li> <li>3. how to open a file on a computer by clicking on the file name or icon</li> </ol>		
<b>Classroom configuration for ICT (simulation) use</b>	<p>Small groups (maximum of three students) on a computer in the computer laboratory</p>		

<b>Resources</b>	<ul style="list-style-type: none"> <li>❖ Ghanaian Physics syllabus for SHS by The Ministry of Education, Science and Sports:2008</li> <li>❖ Peter A. &amp; Henric A.B.Y. (2011), <i>Physics for Senior High Schools in West Africa</i>: Aki-Ola publications: Accra-Ghana. pg 77-78.</li> <li>❖ Laptop</li> <li>❖ Projector</li> <li>❖ Activity sheets</li> <li>❖ Presentation software (Microsoft PowerPoint)</li> <li>❖ Physics laboratory with six computers with the simulation installed on them</li> <li>❖ PhET Simulation entitled <i>PhET/en/simulation/forces-and-motion-basics.html</i></li> </ul> <p>Note: The simulation has already been installed on the computer.</p> <p>Other resources</p> <ul style="list-style-type: none"> <li>• Copies of activity sheets for each group</li> <li>• Pen, paper</li> </ul>
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<b>Lesson Plan</b>		
	<b>Teacher Activity</b>	<b>Student Activity</b>
<b>Introduction</b> (15 minutes)	<p>Teacher reviews student's previous knowledge by asking them the following questions.</p> <p>(1) What is force? (2) State 4 types of force.</p> <p>* Teacher presents some test items (Pre-test) on frictional force to students at the beginning of the lesson. * By use of PowerPoint presentation, the teacher:</p> <ul style="list-style-type: none"> <li>• outlines the lesson objectives to students</li> <li>• gives an overview of the lesson</li> <li>• guides students to open the simulation on their desktops by:</li> </ul>	<p>Students answer the questions orally based on their prior knowledge on forces.</p> <p><b><i>Some expected answers from students.</i></b></p> <p>(1) Force is the pull or push which changes a body's state of rest or uniform motion in a straight line.</p> <p>(2) Types of forces Gravitational force, frictional force, magnetic force, electrostatic force, centripetal force, etc.</p> <p>Students answer the test items based on their prior knowledge on forces.</p> <p>Students open the simulation on friction on their computer</p>

	<ul style="list-style-type: none"> <li>* clicking on the PhET simulation icon on the desktop</li> <li>* select physics</li> <li>* click on the simulation entitled <i>Forces and Motion: Basics (Friction)</i></li> </ul> <p>Note: The PhET simulations are downloaded and installed on the computers in the lab and it is used in the offline mode.</p>	
<p><b>Main Activities</b></p>	<p><b>Activity 1: Definition of frictional force (25 mins.)</b></p> <p>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 perform the following activities:</p> <ul style="list-style-type: none"> <li>• use a snapshot from the simulation environment to help students set up their simulation for activity 1</li> <li>• explore the simulation for five minutes</li> <li>• observe the simulation on friction as they do the exploration</li> <li>• identify the arrows X and Y on the body of mass 50kg as explored in the simulation</li> <li>• record the values of X and Y as shown on the activity sheet.</li> <li>• explain why the body of mass, 50kg did not move when the force X was applied on it</li> <li>• identify the nature of the surface of the floor in contact with the body of mass 50kg as explored in the simulation</li> <li>• define frictional force in their own words</li> </ul> <p>* Teacher asks each group to share their outcomes with the whole class for discussion after activity 1.</p>	<p>Using the snapshot on the activity sheet as a guide, students set the simulation environment as guided by the teacher in order to define frictional force.</p> <p>Students discuss their observations in groups and share ideas among themselves to answer the questions under activity 1 on the activity sheet.</p> <p>Students present their outcomes on activity 1 to the class for discussion by a representative from each group</p>

	<p>Teacher summarizes the key physics concepts in the activity.</p>	<p><b>Expected answers</b></p> <ul style="list-style-type: none"> <li>• X= Frictional force Y= Applied force</li> <li>• X=Y= 45N</li> <li>• there is a force of friction which is equal but opposite to the applied force and this prevents the body from moving</li> <li>• the surface is rough</li> <li>• * frictional force is the force that prevents a body from moving</li> </ul> <p>* it is the force that opposes the motion of a body</p> <p>Students write down the key physics concepts in the activity as the teacher summarizes for revision</p>
	<p><b>Activity 2: Effects of frictional force (25 mins.)</b> Continuing from activity 1, teacher guides the students to identify the effects of frictional force on a moving body using the simulation forces and motion: basics (friction) by performing the following activities:</p> <ul style="list-style-type: none"> <li>• mark the box beside <i>speed</i></li> <li>• increase the applied force to 75N in the simulation (pause the simulation 10 seconds after increasing the applied force to 75N)</li> <li>• state your observations after increasing the applied force to 75N</li> <li>• click on the play button</li> <li>• move the slider on the friction bar closer towards <i>Lots</i></li> <li>• state your observations after performing the activity</li> <li>• state two effects of frictional force based on the activities performed</li> </ul>	<p>Students discuss their observations in groups and share ideas among themselves to answer the questions under activity 2 on the activity sheet.</p>

	<p>* Teacher asks each group to share their outcomes with the whole class for discussion after activity 2.</p> <p>Teacher then calls a representative from each group to present their answers to the everyday life applications of frictional force to the class for discussion.</p> <p>Teacher summarizes the key physics concepts in activity 2 and presents answers to the real- life application questions to students.</p>	<p>Students present their outcomes on activity 2 to the class for discussion by a representative from each group.</p> <p><b>Expected answers</b></p> <ul style="list-style-type: none"> <li>• The body moves after increasing the applied force</li> <li>• The speed of the body also begins to increase</li> <li>• The speed of the body begins to decrease</li> <li>• The force of friction also increases</li> <li>• The force of friction is also greater than the applied force</li> <li>• The force of friction is equal to the applied when the body comes to rest</li> <li>• It decreases the speed of a moving body</li> <li>• It prevents bodies from moving.</li> </ul> <p>A representative from each group presents the answers for whole class discussion.</p> <p>Students write down the key physics concepts in the activity as the teacher summarizes for revision</p>
<p>Conclusion (15 mins.)</p>	<p>Teacher summarizes the key concepts in the whole lesson as follows:  <u><b>Definition of frictional force</b></u>  Frictional force is the force that retards the motion of two or more bodies in contact with each other.  <u><b>Effects of frictional force</b></u>  (1) It decreases the speed of a moving body  (2) It opposes the motion of objects.</p>	<p>Students take notes and then ask questions for more clarification where necessary.</p>

	<p>(3) It prevents surfaces from sliding against each other.</p> <p><b><u>Daily life application of frictional force</u></b></p> <p>(a) It makes braking action of vehicles possible</p> <p>(b) It is applied in the sharpening of cutlasses</p> <p>(c) It keeps the feet from sliding during walking</p> <p>Teacher then ends the lesson by giving out:</p> <ul style="list-style-type: none"> <li>• The same test items given to students at the beginning of the lesson for them to redo</li> <li>• Assignment sheets to students</li> </ul>	<ul style="list-style-type: none"> <li>• Students redo the test as a way of assessing themselves on the physics concepts discussed during the lesson.</li> <li>• Students take assignment sheets to be solved as homework.</li> </ul>
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**PHYSICS (SHS 2)**  
**FRictionAL FORCE**

**Introductory Activity Sheet (Pre/post-Test)**

1. The following questions point out the definition of frictional force. Fill in the blank space with the appropriate term.
  - (a) The force that must be overcome for a body to move on a rough surface is called .....  
.....
  - (b) The force that overcomes the opposing force of a body is called .....  
.....
2. Indicate whether the statement below is true or false:  
Frictional force is the retarding force between two surfaces in contact. **True / False.**
3. The following statements outline the effects of friction. Indicate whether the statements below are true or false.
  - (a) A body will always move independent of the applied force and the surfaces in contact.  
**True / False.**
  - (b) The opposing force decreases the rate at which a body moves. **True / False.**

**PHYSICS (SHS 2)**  
**FRICITIONAL FORCE**  
**Activity Sheet**

**Introduction**

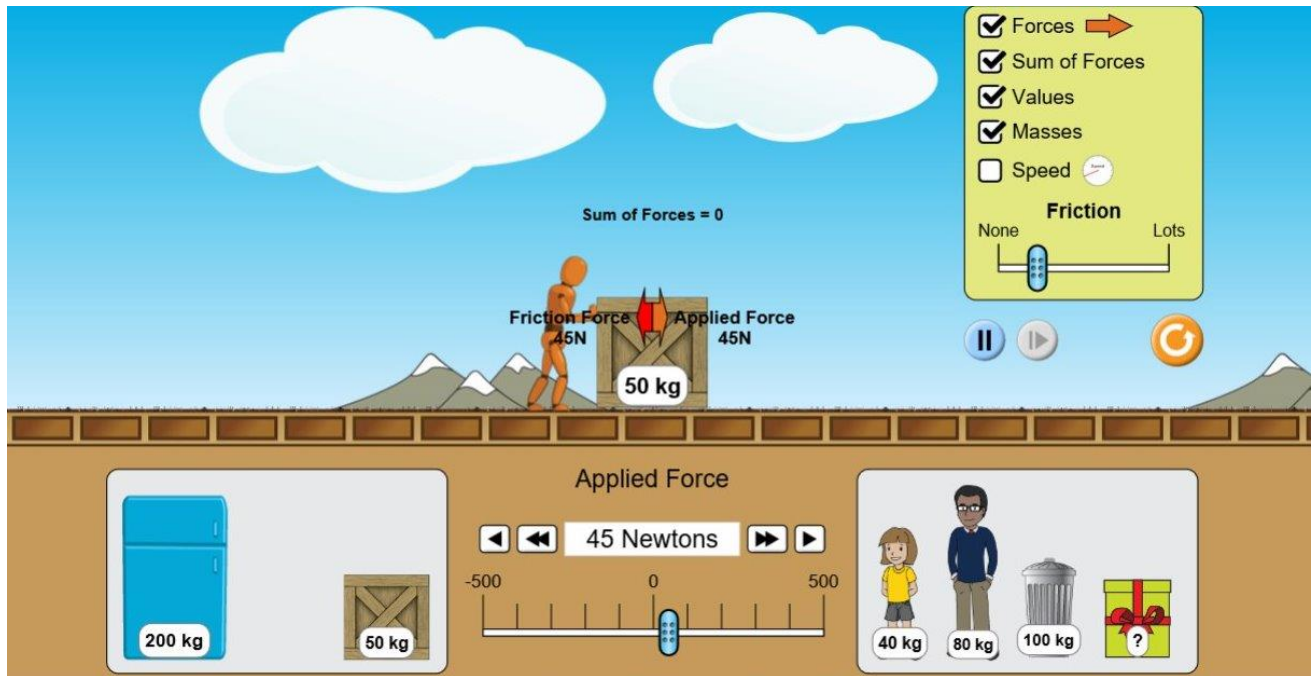
The activity sheet you have been given is in two sections: activity 1 and activity 2. These activities are designed based on the simulation *forces-and-motion: basics (friction)* aimed at helping you to define frictional force in your own words and state at least two effects of frictional force and then apply your understanding of frictional force in everyday life situations.

Note: work in groups

***Activity 1: Definition of frictional force***

This activity is to help you come out with the definition of frictional force by exploring the simulation on *forces-and-motion: basics (friction)*.

- (a) Open and explore the simulation on *forces-and-motion: basics (friction)* for five minutes.
- (b) Set your simulation environment as the picture below and answer the questions that follows



- (i) Identify the arrows below as explored in the simulation



X .....

Y .....

(ii) Record the values of X and Y in (i) above.

X= .....

Y= .....

(iii) From the simulation, why did the body of mass 50kg not move when the force X was applied on it.

.....  
.....  
.....  
.....

(iv) What is the nature of the surface of the floor in contact with the body of mass 50kg as explored in the simulation

.....  
.....

(v) In your own words, define frictional force.


.....  
.....  
.....  
.....

**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.

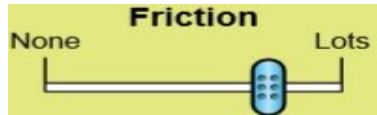
(Pause the simulation 10 seconds after increasing the applied force to 75N by clicking on the pause button , in the simulation)

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.

.....  
.....  
.....  
.....  
.....

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

- 1.....  
.....
- 2.....  
.....

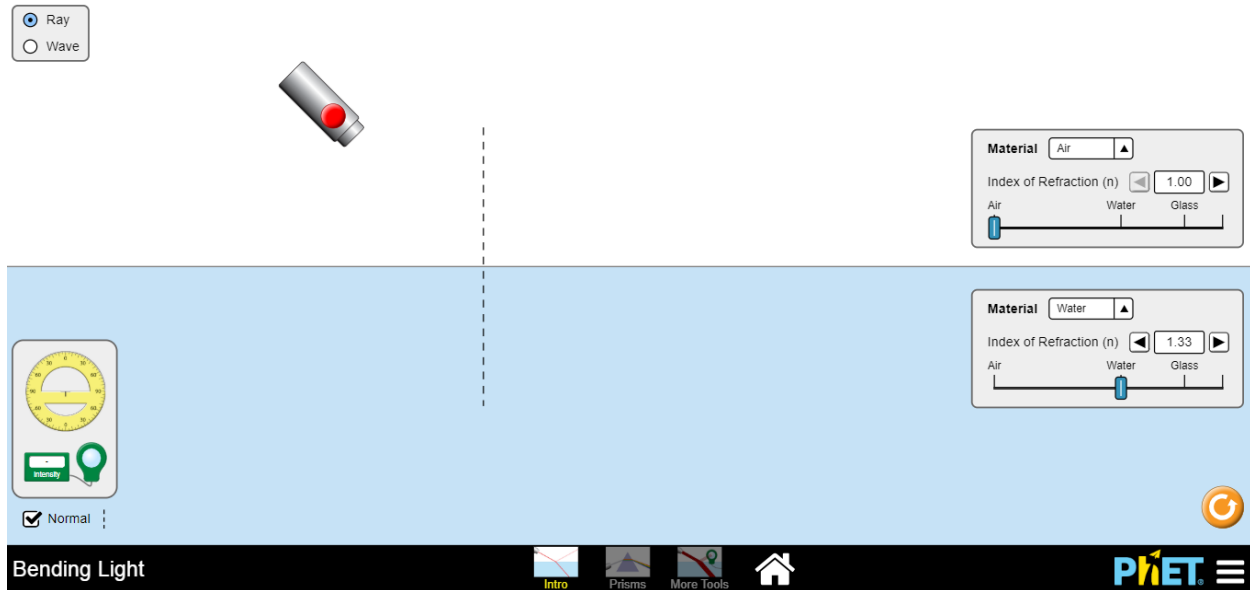
Real-life application of frictional force

State two applications of frictional force in everyday life.

- (1) .....
- (2) .....

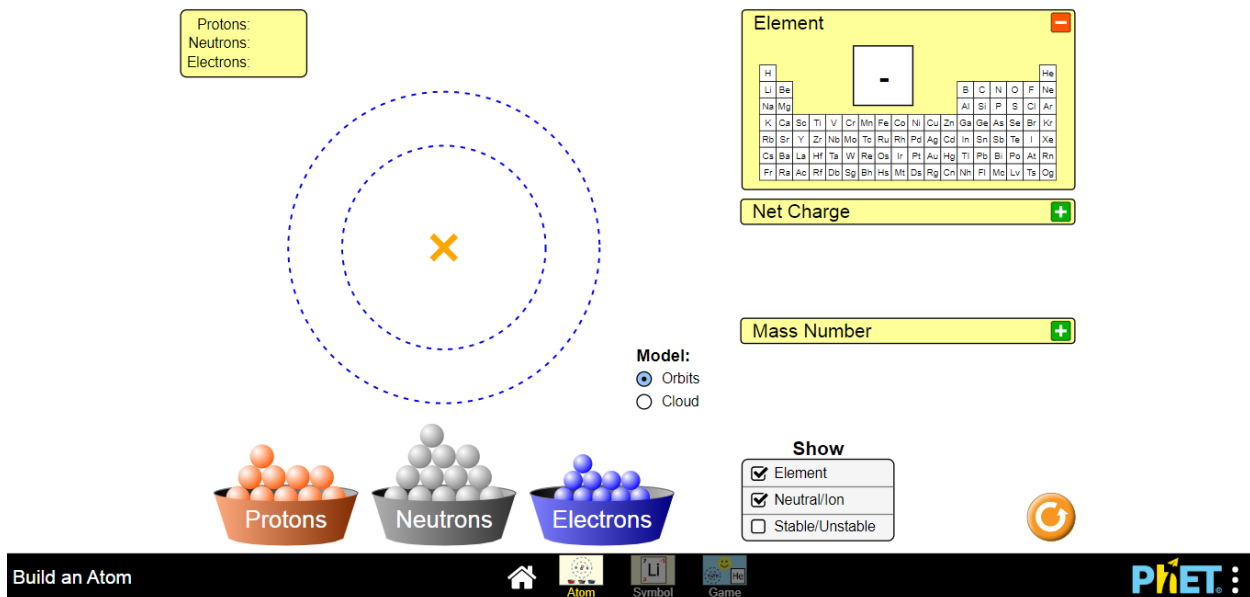
## APPENDIX E: FUNDAMENTAL INTERFACES OF PhET SIMULATIONS USED IN THE DESIGN OF THE FOUR PSSPLS BY THE PRE-SERVICE TEACHERS

### E1: Bending Light (BL) PhET simulation interface



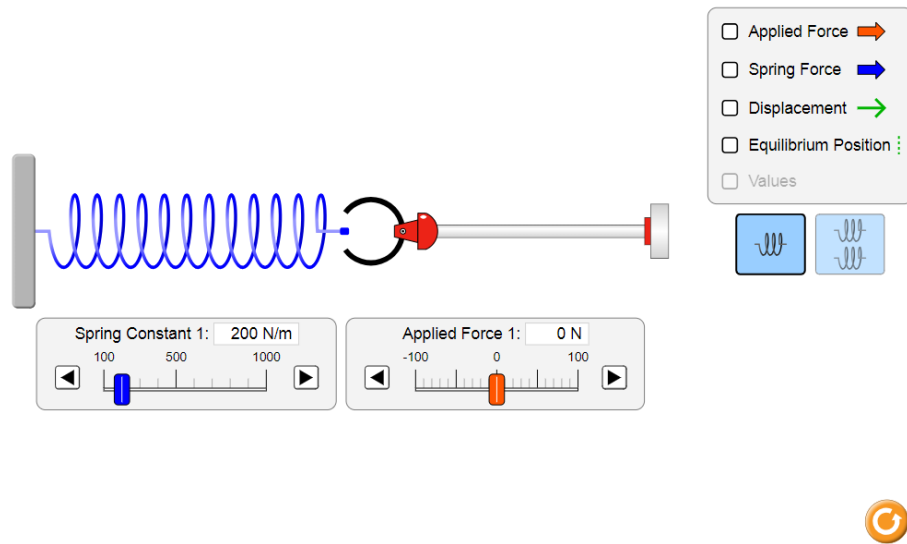
Downloaded from: [https://phet.colorado.edu/sims/html/bending-light/latest/bending-light\\_en.html](https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html)

### E2: Build an Atom (BA) PhET simulation interface



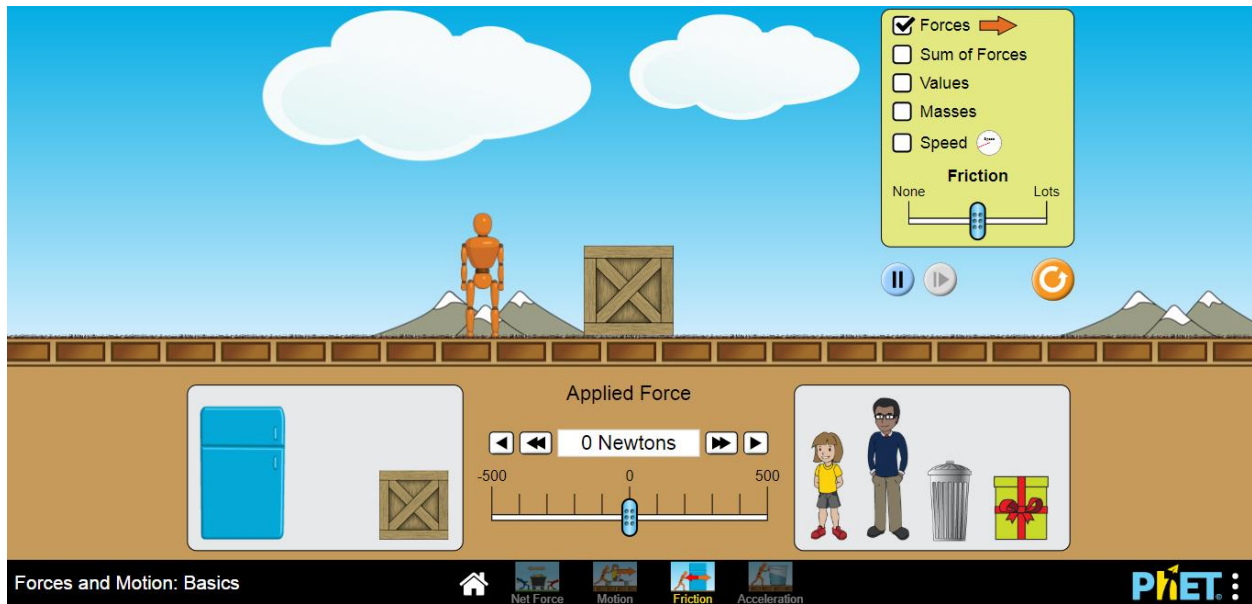
Downloaded from: [https://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom\\_en.html](https://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_en.html)

### E3: Hooke's Law PhET simulation interface



Downloaded from: [https://phet.colorado.edu/sims/html/hookes-law/latest/hookes-law\\_en.html](https://phet.colorado.edu/sims/html/hookes-law/latest/hookes-law_en.html)

### E4: Force and Motion: Basics (Friction) PhET simulation interface



[https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics\\_en.html](https://phet.colorado.edu/sims/html/forces-and-motion-basics/latest/forces-and-motion-basics_en.html)

APPENDIX F: SAMPLE CODED LESSON PLAN DOCUMENTS

F1: Example of coding done in PSSPL\_1 lesson plan document (developed by DTA1)

<p>TPACK</p>	<p>Activity 2: Verification of Snell's law (laws of refraction) (30minutes)</p>	
	<p>In order for students to construct their own knowledge on how to verify the laws of refraction, teacher guides students to do the following in groups:</p> <ul style="list-style-type: none"> <li>▶ Use a snapshot from the simulation environment to help students to setup their simulation for activity 2 in relation to the simulation element such as material, ray and the protractor option</li> <li>▶ With the help of the protractor, set the angle of incidence (<math>i^\circ</math>) to <math>10^\circ</math> measure and record the corresponding angle of refraction.</li> <li>▶ Repeat the above step with <math>i^\circ = 20, 30, 40</math> and <math>50</math> and measure the corresponding angles of refraction for each value</li> <li>▶ Compute and record the sine of the angles of incidence and refraction in the activity 2 sheet.</li> <li>▶ Determine the average of the values of <math>\frac{\sin i}{\sin r}</math> and state what it represents</li> </ul>	<p>TPK</p> <p>Based on the snapshot which has been pasted in the activity sheet, students set up the simulation environment as guided by the teacher in order to verify the laws of refraction. And then answer questions on the activity sheet that fall under activity 2 based on their prior and newly acquired knowledge.</p> <p>TCK</p>

F2: Example of coding done in PSSPL\_2 lesson plan document (developed by DTB1)

<p style="text-align: center;">TPACK</p>	<p><u>Activity 2</u>                  In this activity, teacher guides students to find out the mass number and the net charge of element. Teacher guides students to do the following in groups.</p>	<p>Students explore the simulation environment by following the instructions on the worksheet to answer the questions on activity 2 in groups.</p>
	<ul style="list-style-type: none"> <li>• Close the simulation and reopen it.</li> <li>• On the net charge and mass number bar which is below the element bar, click on the positive sign to change to negative sign.</li> </ul>	<p style="text-align: center;">TK</p>
	<ul style="list-style-type: none"> <li>• Use the protons (p) and neutrons (n) to find the mass number of each element by dragging one proton and one neutron at a time.</li> </ul>	<p style="text-align: center;">TCK</p>
	<p>Teacher discusses the questions on the activity 2 and briefly highlights on the key points.</p>	<p>Students contribute to the discussion and write down the key points.</p>
	<p><u>Activity 3</u>                  In this activity teacher guides students to classify the elements into metals, metalloids, non-metals and rare/Inert gases by using the simulation.</p>	<p>Students explore the simulation by following the instruction on the worksheet as well as using their prior (new) knowledge constructed in activity 1 to answer the questions on activity 3 in groups.</p>
	<p>Teacher guides students to do the following in groups.</p> <ul style="list-style-type: none"> <li>• Close the simulation and reopen it.</li> <li>• Add one proton to the atom and note the group of the element that appears on the periodic table.</li> </ul>	<p style="text-align: center;">TPACK</p>

## APPENDIX G: ETHICAL CLEARANCE LETTER



Faculty of Education

11-May-2017

Dear **Elizabeth Darko Agyei**

**Ethics Clearance: Tracking the development of pre-service teachers' competencies for integrating information and communication technology in the teaching of high school physics in Ghana**

Principal Investigator: **Elizabeth Darko Agyei**

Department: **Education (Bloemfontein Campus)**

### APPLICATION APPROVED

With reference to your application for ethical clearance with the Faculty of Education, I am pleased to inform you on behalf of the Ethics Board of the faculty that you have been granted ethical clearance for your research.

Your ethical clearance number, to be used in all correspondence is: **UFS-HSD2017/0565**

This ethical clearance number is valid for research conducted for one year from issuance. Should you require more time to complete this research, please apply for an extension.

We request that any changes that may take place during the course of your research project be submitted to the ethics office to ensure we are kept up to date with your progress and any ethical implications that may arise.

Thank you for submitting this proposal for ethical clearance and we wish you every success with your research.

Yours faithfully

Dr. MM Nkoane  
Chairperson: Ethics Committee

Education Ethics Committee  
Office of the Dean: Education  
T: +27 (0)51 401 9683 | F: +27 (0)86 546 1113 | E: NkoaneMM@ufs.ac.za  
Winkie Direko Building | P.O. Box/Posbus 339 | Bloemfontein 9300 | South Africa  
www.ufs.ac.za



**APPENDIX H: LETTER FROM LANGUAGE EDITOR**

**UNIVERSITY OF CAPE COAST**  
**COLLEGE OF HUMANITIES AND LEGAL STUDIES**  
**FACULTY OF ARTS**  
**DEPARTMENT OF COMMUNICATION STUDIES**  
**(WRITING UNIT)**

Tel: 03321-30914  
Email: [desucc@gmail.com](mailto:desucc@gmail.com)  
Our Ref: *DCS/W/1/43*  
Your Ref:



University Post Office  
Cape Coast, GHANA

29<sup>th</sup> January, 2019

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**TO WHOM IT MAY CONCERN**

**PROOF OF EDITING**

This is to certify that I have read and thoroughly edited all chapters of the thesis “TRACKING THE DEVELOPMENT OF PRE-SERVICE TEACHERS’ COMPETENCIES FOR INTEGRATING INFORMATION AND COMMUNICATION TECHNOLOGY IN THE TEACHING OF HIGH SCHOOL PHYSICS IN GHANA” by Mrs. Elizabeth Darko Agyei. It is hoped that the candidate will consider my suggestions in the revision of her draft in consultation with you.

Thank you.

Sincerely,

A handwritten signature in black ink, appearing to read 'Wincharles Coker', with a large, stylized flourish at the end.

Wincharles Coker (PhD)

**Coordinator, Writing Centre**

Department of Communication Studies