Promoting Interactive Teaching with ICT: Features of Intervention for the Realities in the Ghanaian Physics Senior High School Classroom

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Abstract—This research was purposed to determine the features of an information and communication technology (ICT)-based intervention that promotes interactive teaching and fits the realities of the Ghanaian senior high school physics classroom context. By a critical review analysis of 13 research studies that had a focus on ICT use in science education, simulations use as an instructional tool, interactive teaching approaches with ICT, and frameworks for ICT integration, the study advocates that intervention with inherent features comprising of: a readily available, sustainable, context- and content-specific ICT teaching and learning environment; an ICT-oriented knowledge base for teachers' uptake of ICT; and underlining framework for defining interactive learner-centered teaching approach with ICT; ICT-driven interactive lesson objectives; an inquiry-driven, activity- and ICT-based learning material; and a collaborative classroom arrangement is appropriate and sensitive to the needs of the Ghanaian physics classroom context and, hence, possess the potential for promoting interactive teaching. Situated in the specific context of the research and implications of the findings, the intervention features are discussed.

Keywords—high school, ICT-based intervention, interactive teaching, physics, simulations

1 Introduction

The need for educational quality positions information and communication technology (ICT) as an essential instructional tool for the prospects of interactive teaching. ICT use in the classroom goes beyond exploring and studying its techno-centric capabilities [1] to enhance teaching and learning processes in the classroom context. Literature shows that ICT, when used appropriately, incorporates real-life situations in the teaching and learning process [2]; increases "access to education" [3]; promotes computational thinking [35]; provides an interactive, flexible, and convenient platform for learner-centered teaching and learning atmosphere as well as motivates learners to be actively involved in the instructional process with expectant readiness to acquire new knowledge and skills [4], [5], [2], [31]. These potentials seem to situate

ICT as a potential vehicular tool for promoting interactive teaching in the physics classroom. Studies [6], [7], [8] on ICT integration in physics classrooms have highlighted the fact that ICT-based resources such as simulations, among others, have the potentials that encourage learners to explore through their inquiry; form a sharp metal framework, and facilitate improvements in students' understanding of concepts in physics. That notwithstanding, ICT, when used in the physics classroom, stimulates teachers to be facilitators. Irrespective of the potentials of ICT as mentioned herein, most physics teachers at the senior high school (SHS) level of education in Ghana are not using ICT in their teaching practices owing to their deficiency in ICT-oriented knowledge and pedagogical skills [29]. Most teachers prefer to adopt a non-interactive teacher-centered approach for teaching physics at the SHS level [9], [10]. Their affection for this approach has been deeply rooted in their respective teacher training institutions in Ghana. Lewin and Stuart [30] supported this assertion by observing that "the dominant pedagogical stance in Ghana remains one where trainees are largely regarded as 'empty vessels' with little knowledge or experience of teaching." The consequence of this action is reflected in the poor performance recorded for physics in the West African Senior Secondary Certificate Examination (WASSCE) in recent years and the dwindling interest in the subject [32]. As teachers' ICT skills and experiences with technology is a contributing factor to their uptake of technology into their instructional practices [32], perhaps, the solution to these critical concerns would be to equip teachers with the needed ICT-oriented knowledge and pedagogical skills in order to effectively incorporate ICT in their teaching practices as well as develop interactive learner-focused teaching and learning materials which are ICT-driven and sensitive to the Ghanaian SHS physics classroom context. Such an initiative would require the design of an interventional guide in the form of ICT-based exemplary curriculum materials with the intent to provide both pre-service and in-service teachers with practical and authentic samples of what an ICT-based innovation constitutes. Curial to this task is what such an intervention should encompass in order to foster teachers' ICT-based competencies for effective physics teaching.

Informed by these concerns, the present study employed a systematic review methodology intending to determine the features of an intervention that best fit the realities in the Ghanaian SHSs as well as prepare teachers to effectively design, develop and implement ICT-based curriculum materials in the form of physics lessons using simulation as an interactive ICT tool. The features identified through critical analysis of relevant literature were used as guidelines for developing two sets of ICT-based interventions. In this study, we report on and examine the inherent features of the ICT-based interventions to provide valuable insights into the extent to which they promote interactive teaching of physics and fit the Ghanaian classroom context. The article is organized as follows: an introduction that provides insight into the research problem and outlines the research objectives. This is followed by a literature review that focuses on the potentials of ICT in science classrooms, emphasizing simulation uses in physics classrooms, its benefits, the implication for teachers, and frameworks that govern its use as an instructional ICT tool. In the subsequent sections, we outline the research question, describe the methodology employed, and present the study results. The article ends with a discussion and a conclusion based on the results.

2 Literature review

In this section, literature is reviewed and discussed concerning: 1) potentials of ICT use in education and its implication for teachers, 2) simulation uses as an instructional ICT tool—looking at its benefits and implication for teachers, and 3) frameworks for using interactive simulations. Discussions about the latter are purposed to situate Technological Pedagogical and Content knowledge (TPACK) and Five Dimensions for Meaningful Learning with ICT (5DML_ICT) models as theoretical underpinnings needed for equipping teachers with ICT-oriented knowledge and pedagogical skills that are interactive. The review has been done herein to provide valuable guidelines and information on appropriate features to consider for developing an ICT-based intervention that meets the needs of the Ghanaian classroom context.

2.1 Potentials of ICT use in science education and its implication for teachers

The affordances of ICT in education are vital to bringing about transformational change for effective teaching and learning process in a constructivist outfit. Studies in the area of ICT integration into science teaching, for instance, have echoed the potentials of ICT-based resources, such as simulations, animations, videos, etc. to include the provision of an alternative transmission; better explanations of various concepts in science that otherwise look very abstract; and modernity which is relevant to students [36], [37]. These suggest that by incorporating ICT into the teaching of physics and science in general, a typical teacher-centered 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 the teaching of physics. That notwithstanding, the impact of ICT on physics teaching for positive results is inevitably dependent on its use in the classroom [38]. This suggests that teachers' roles in such an ICT revolution in education are crucial to realizing and appreciating the affordances and impact of ICT as an instructional tool in education, especially 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. This suggests that examining pedagogy in light of ICT requires considering what a selected ICT learning resource affords the learner and the teacher when used in instruction.

The literature discussed herein emphasizes that ICT, when used in the classroom, has many implications for teachers regarding the ICT-oriented knowledge they need to identify, the appropriate ICT resources to use and the instructional approaches to adopt for meaningful learning to occur with ICT. This suggests that a specific ICT resource, ICT-oriented knowledge and ICT-informed pedagogy are necessary ingredients for teachers' uptake of ICT. Hence, these elements as situated in the literature could serve as possible features to be considered for the design of ICT-based interventions that promote interactive teaching. Subsequently, these elements are discussed based on literature to establish their relevance.

2.2 Benefits of simulations in science (physics) classrooms

Simulations are highly recommended ICT resources for the creation of interactive teaching and learning environments [40]. According to Wieman et al. [23], simulations can provoke students to think deep into the concepts they are being taught and allow them the opportunity to understand abstract concepts in physics. This suggests that, with simulations, the essence of ICT is brought to bear for: a) the development of solid conceptual understanding in various topics in physics, b) piquing the interest of students towards the subject, and most certainly, c) promoting constructiveness in physics classrooms in such a manner that provokes good achievement levels in the subject. Benefits such as these situate simulations as a possible ICT resource to consider for the development of an intervention that promotes interactive instructional discourse.

Several simulation software have been developed to promote effective physics teaching at the high school level. Physics Education Technology (PhET), for example, is a suite of interactive computer simulations [39] 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 science subjects like biology and chemistry (http://phet.colorado.edu). As a targeted simulation environment [16], PhET simulations (PhETs) are designed to provide an interactive platform that engages students to learn through exploration and discovery and also help students to connect real-life phenomena to the underlying subject matter in a particular science [39]. With a purpose to introduce students to new and interactive ways of studying physics, PhET could be described as the "possible for the impossible" when it comes to physics learning—meaning, it could very well be a substitute for the abstract concepts in physics that cannot be visualized in the real-world (e.g., the properties of gases and the atomic structure). PhETs could be taken as a substitute for the sophisticated operational physics laboratory usually envisioned by educational stakeholders—which seems ordinarily challenging to acquire due to the financial constraints that come with it; primarily, in the African context.

Furthermore, PhET is a popular ICT instructional tool among the sciences since it is free—users need not pay any amount to enjoy its use. It is a java-based software 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. These characteristics situate PhET simulations as an appropriate feature for an ICT-based intervention design for the context of the study.

2.3 Simulation as an interactive instructional ICT tool: The teacher's role

When used in science classrooms, the potentials of simulations are greatly influenced by how they are used in the teaching and learning process. The teacher's role in this respect is perhaps, inevitable in that, for effective use of simulations that promote interactive teaching and meaningful learning, its use must be focused to 1) supplement other instructional strategies and not to replace; 2) facilitate a student-centered model of instruction; 3) highlight the limitations or weaknesses in the simulations employed; and 4) bring the content into focus, not the technology (simulations) [11]. These guidelines seem to give insights into the kind of pedagogical approach to adopt with simulations. In Sahin's [12] view, the pedagogical approach in this respect could be either instructive or constructive. Sahin [12] 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, that constitutes a constructive way of using simulations. Other methods mentioned in the literature include simulations' use in the science classroom to allow for prediction, observation, exploration, analysis, verification, and explanation [13], [14], among others. With these teaching methods, it appears that the pedagogical approach for the integration of simulations into teaching practices could be highly dependent on the teachers' preferences—which might be subject 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 are to be situated should also be taken into consideration. The strategies to adopt in using simulations for teaching science might not be as easy as it seems [15]. According to [15], it would require careful planning and critical decisions to use simulations effectively and secure the anticipated learning outcomes. This assertion seems to highlight the need for a 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 promotes interactive teaching in the science (physics) classroom.

2.4 Frameworks for using interactive simulations in instruction

Research conducted concerning the interactive teaching of physics and science, which used simulation as an ICT tool or as a vehicle for implementing the change process with ICT, 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 [16] proposed a framework for using interactive simulations in an educational setting. According to [16], the simulation, assignment, and environment are three significant elements influencing students' use of the simulation. Kaheru and Kriek [17] also examined the use of interactive computer simulations as a means of 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 active mindedness in the learner [18]; and the multimedia theory of learning which advocates that learning as a process is not without the participation and active interaction [19]. Furthermore, de Jong [7] defined learning with simulations as "involving an inquiry cycle consisting of processes such as hypothesis generation, experiment design, data interpretation, and reflection." Though these frameworks advocate different theoretical grounds based on which a simulation environment could be incorporated as an instructional ICT tool for effective teaching and learning, the teacher seems not essential. Therefore, it is unclear what the teacher's role would be, nor how teachers could take up teaching with simulations under the umbrella of these frameworks. Rehn et al. [16], for instance, agreed that the teacher is a vital resource. However, in their proposed framework, the teacher element was not considered even though they mentioned 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 considered, 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 research about the choice of framework to adopt in the design of the ICT-based interventions. In particular, two theoretical frameworks informed the design of the interventions, namely, "technological pedagogical content knowledge (TPACK)" by Mishra and Koehler [20] and the "five dimensions for meaningful learning with ICT" by Howland, Jonassen, and Marra [21]. In the following sections, these frameworks are discussed based on literature to provide a substantive understanding of how each one of the frameworks was elucidated as a feature for designing the interventions discussed in this research.

Technological Pedagogical Content Knowledge—Mishra and Koehler [20] noted that the development of theory brings into educational technology and teaching, as involved in teacher education, an added level of complexity characterized by many types of knowledge. They further explained that embedded in the complexities of teacher knowledge are specific fundamental components that, apart from what each one brings to the forefront of educational technology, present a complex interaction or relationship among themselves to grant teachers the opportunity to develop ICT-oriented competencies [22]. Based on this, [20] proposed that pedagogy, content, and technology are the three core components of good teaching. From Mishra and Koehler's [20] perspective, a successful teacher in the classroom 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 called "Technological Pedagogical and Content Knowledge (TPACK)."

In this research, TPACK was considered as the knowledge teachers need to drive interactive prospects with ICT and design ICT-based interventions. In particular, the technology that was learned and explored for the design of the interventions was Physics Education Technology (PhET) simulations and was chosen on the basis that; it is readily available; user friendly; has the potential to be sustained in Ghana; enhances the efforts of a teacher [23]; and provokes independent, critical and computational thinking [24], [41]. The content was physics. The research adopted an interactive pedagogical strategy that is constructive. Based on these operationalizations, the TPACK model was adapted for the design of the intervention and situated in the 'Ghanaian senior high school physics classroom' (GSHSPC) context, as shown in Figure 1.

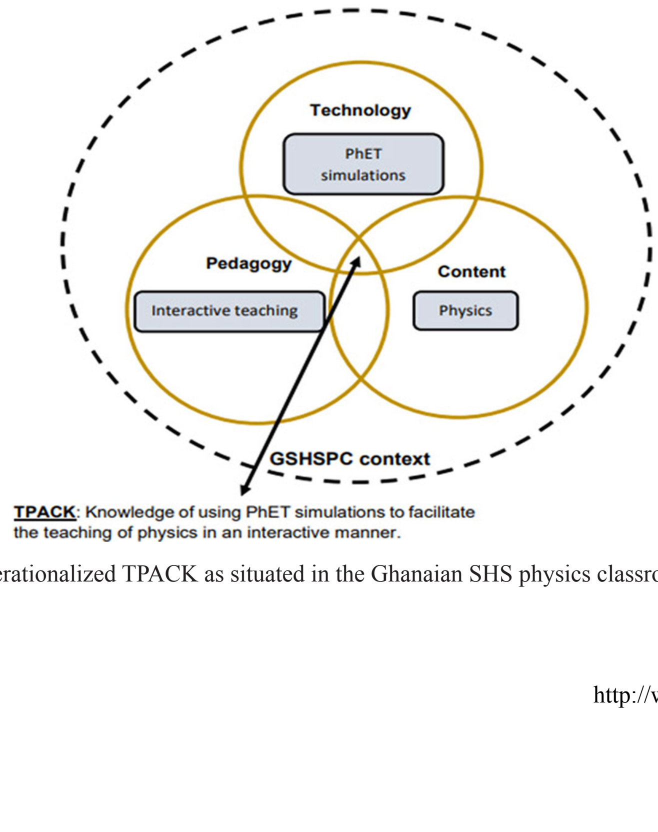


Fig. 1. Operationalized TPACK as situated in the Ghanaian SHS physics classroom context

Five Dimensions for Meaningful Learning with ICT (5DML-ICT)—The five dimensions for meaningful with ICT (denoted by 5DML-ICT as in [33]) framework advocates five "interrelated, interactive and interdependent" [25] dimensions, namely, active, constructive, authentic, intentional and cooperative that need to be considered when ICT is used as a vehicular tool for achieving meaningful learning outcomes in the classroom [21], [26]. From the perspective of Jonassen et al. [26], for example, the active dimension is defined by the creation of an environment that fosters learners to be engaged in the manipulation of objects as well as observing the changes that emanate from their manipulations in learning the subject matter of interest; constructive dimension is founded on the provision of learning structures that encourage learners to articulate what they have accomplished and also, reflect on tasks assigned to them in learning the subject matter; intentional dimension is purposed for achieving a cognitive goal; authentic dimension emphasizes the establishment of a connection to the world outside the classroom; then the cooperative dimension emphasizes the provision of collaborative arrangements to stimulate educative conversations among learners in a way that helps learners to learn from each other. These descriptions seem to echo the characteristics of interactive teaching [33]:

> "… *a teaching method that is learner-centered, with teachers creating various avenues and structures that are ICT-oriented in ways that stimulate learners to be active, constructive, authentic, intentional and cooperative in a constructivist teaching and learning environment*."

In [33], the 5DML-ICT framework was conceptualized as "dimensions of interactivity"; whereby the active, constructive, authentic, intentional, and cooperative dimensions were defined with an emphasis on the use of ICT in instruction for 1) engaging "learners in learning the subject matter," 2) stimulating learners "to reflect upon the subject matter and express their ideas and meaning beyond what is presented to them," 3) connecting learners' "personal experiences to the real world," engaging learners in "diagnosis, evaluation, and improvement of their learning gap," and encouraging group work among learners "for divergent knowledge expressions" respectively. These definitions, perhaps, situate the 5DML-ICT framework as a possible roadmap by which ICT could be used in the classroom to promote interactive teaching. Furthermore, the literature discussed so far seems to suggest in different words that the 5DML_ICT framework champions a kind of teaching strategy as well as a learning process that is, among others, activity-oriented; student-centered; real-world linked; goal-oriented and highly collaborative and, hence, seems to echo the constructivist ideologies. Perhaps, the latter element aligns with Vygotsky's [27] constructivism, which emphasizes the importance of the social context in learning and, hence, advocates a collaborative dimension to teaching for the purpose of promoting social interactions in the classroom. Conceivably, the five dimensions do not only position the teacher as a guide [28], but also, propel students to help each other foster their understanding of concepts that they would not understand on their own under normal circumstances. In the current research, the elements elucidated based on the critical analysis of the literature discussed herein were considered vital features for the design of ICT-based that reflect the characteristics of interactive and learner-centered teaching approaches.

3 Research question

As the primary goal of this research was to determine the features of an ICT-based intervention that fits the Ghanaian SHS physics classroom context and also promotes interactive teaching of physics, the literature discussed in this article was used as a lens to address the research question: *What are the features of an ICT intervention that can be designed to fit the realities in the SHS classroom in a manner that makes the teaching of physics interactive in Ghana?*

4 Research methodology

A systematic review methodology was employed in conducting this research using Khan, Kunz, Kleijnen, and Antes' [44] systematic review ideas as a guide. A review question was first identified; this constituted the research question for the current study and hence, served as a roadmap for making decisions about the types of studies to consider for the review. Electronic sources such as Google, Google Scholar, Research Gates, Springer, and SAGE databases were searched for relevant English literature using keywords such as "physics teaching in Ghana," "ICT use in education," "interactive teaching methods," "meaningful learning with ICT," "simulations use in physics instruction," "ICT use in physics classrooms in Ghana," etc. Initially, 34 studies were broadly selected based on their association to literature in physics education in Ghana, ICT use in education, and frameworks for ICT integration. These were cross-referenced to eliminate repeated references and were further screened to include only studies (total of 13) that focused on the potentials of ICT use in science (physics) education and its implication for teachers, simulations use as an instructional tool. Interactive teaching approaches with ICT and ICT frameworks and approaches for developing teachers ICT-oriented knowledge and pedagogical skills. The 13 selected studies were then critically analyzed and summarized based on their respective backgrounds, results, findings, and conclusions. The findings of the review process were then used as a lens to identify the appropriate and interactive features to consider for the development and design of an ICT-based intervention that fit the Ghanaian context.

Based on the review results, two sets of intervention design, namely, *ICT-based intervention 1* (ICTBI1) and *ICT-based intervention 2* (ICTBI2), was developed and produced based on the Ghanaian physics curriculum for SHS. These were PhET simulation-based physics lesson artifacts—lesson plan document, activity sheet, and presentation slides. In particular, interventions ICTBI1 and ICTBI2 were designed based on the topics: *wave motion* and *formation of images by a bi-convex thin lens*, respectively.

The interventions were given to two experts to appraise. The views and suggestions from the experts were used to revise and improve the quality of the interventions accordingly. The purpose of the appraisal was to ensure practicability and improve the validity of the interventions.

5 Research results

To address the research question, the two sets of interventions were examined to determine the features that best fit the realities in the Ghanaian SHS physics classrooms for interactive teaching of high school physics.

Based on the literature review, the features that emerged as fit for the Ghanaian SHS physics classroom context and hence, governed the development of the interventions were as follows:

- An ICT teaching and learning environment 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 such as PhET simulation environment [16], [23], [24].
- A knowledge base that is ICT-oriented and has the potential to foster a teacher's capacity and ability to draw from pedagogy, content, and technology to establish a relationship between them; for example, TPACK [20].
- A framework(s) that explicitly defines interactive teaching with ICT in a way that situates the learner as the focus in the physics classroom; for example, the 5DML_ICT framework [33], [21].
- An activity-oriented learning material that employs the affordances of a selected ICT tool in an exploratory self-directed inquiry or a demonstrative form of inquiry to facilitate and enhance learners' learning and conceptual understanding of the subject matter [4]; for example, activity sheet.
- Lesson objectives that are interactive, ICT-driven, and chosen purposefully to support the "specific learning objectives" as defined in the physics curriculum [19].
- A collaborative classroom arrangement (CCA) in the design of lesson artifacts for the enforcement of social interactions and teamwork capabilities in learners [26], [27].

In the sections that follow, each of these features is presented and explained for the specific context of this research.

5.1 Physics education technology simulation (phets) environment

PhET simulation served as the interactive ICT tool feature for the design of the interventions in this research. This was because it was readily available (i.e., free and downloaded from the PhET website and used offline on a computer). This makes 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 interfaces that allow a user or a learner to easily explore and interact with it in order to discover and learn about its content-driven affordances for a specific representation of a subject matter of choice. Subsequently, we overview each of the two PhET simulation environments used in the interventions' design. This is intended to highlight their respective affordances in order to show how they informed the design of the interventions ICTBI1 and ICTBI2.

The PhET simulation environment, entitled: *Wave on a String* (denoted as WS), was used to design and develop the lesson artifacts for *Wave motion*, which produced intervention ICTBI1. Figure 2 shows the new interface of the WS PhET.

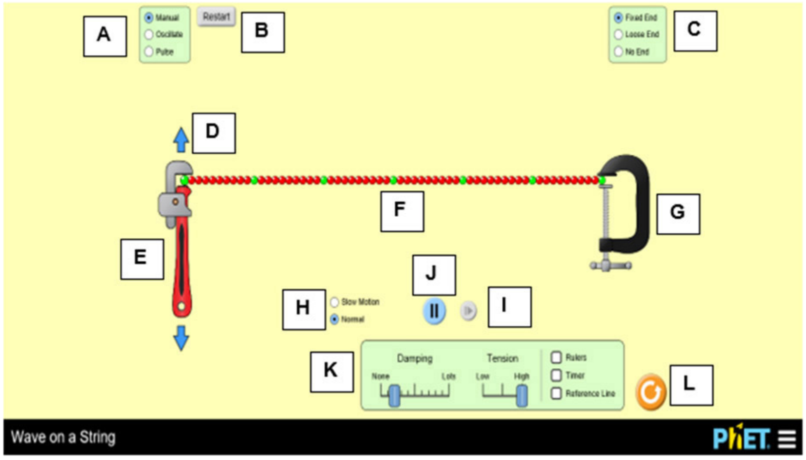


Fig. 2. Snapshot of unexplored WS PhET simulation environment
(taken from http://phet.colorado.edu)

Labels **A** to **L** (in Figure 2) were added to the simulation interface to reference its interactive features in explaining their affordances.

Each feature of the *WS* simulation environment is designed for a specific purpose in representing 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 2—this provides an interactive atmosphere for waves to be generated manually by use of a wrench (i.e., feature **E**). The wrench is designed to 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 propagation medium is a string with its particles represented by the red and green balls. The refresh button (labeled **L**) is designed to bring the simulation environment to its initial interface during exploration where necessary. The feature labeled **G** in the simulation environment mimics a G-clamp and provides a fixed end to the string when the *Fixed End* option is selected from tab **C** as shown in Figure 2. 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** lets the learner/user slow down the simulation feedback during exploration or allows the simulation to give feedback in its normal mode. Features **J** and **I** allow for the simulation environment to be paused and forwarded respectively where necessary. **K** is also a multiple-purpose tab with different features with different functions to represent 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 to introduce 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 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 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; *Reference line*—when checked provides the user with a dotted line to assist in taking accurate readings using the ruler feature. As indicated in tab C, the options *Loose End* and *No End* provide a loose end for the string by using 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* and the specific learning objectives (see Figure 3) set for the intervention, ICTBI1. With consideration for time and the realities in the Ghanaian SHS classroom, three specific objectives were outlined to be achieved with the ICTBI1 intervention. These objectives were adapted from the Ghanaian physics curriculum for SHS to ensure that the intervention aligned with the stipulations of the curriculum concerning the physics content.

Specific Objectives	At the end of the lesson, students should be able to: ▪ explain waves as a transfer of energy and not matter. ▪ describe measurable waves properties such as amplitude and wavelength ▪ describe how amplitude and wavelength affect waves.

Fig. 3. Excerpt from lesson plan document showing the learning objectives that were chosen for ICTBI1

In particular, in tab **A**, the *Oscillate* option (see Figure 2) of the *WS* simulation environment was considered helpful in achieving the learning goals with the other supporting features of the simulation interface. When selected, the *Oscillate* option provides an authentic, interactive platform for measurable properties of a wave such as *Amplitude*, *Frequency*, and even *Wavelength* to be practically explained. It also provides an avenue for learners to appreciate the relationship that exists between these measurable properties.

The second PhET simulation environment employed for the intervention design, ICTBI2, is entitled: *Geometric Optics* (denoted as *GO*). *GO* also has interactive features (i.e., tabs, menus, sliders, etc., as indicated in Figure. 4) as observed in the *WS* simulation environment. However, it is different in terms of the physics concepts it mimics. For example, in this research work, it was used in the design of ICTBI2 for achieving two learning goals under the topic: *Formation of images by a bi-convex thin lens* in order to help learners describe:

1. the characteristics of the image formed by a converging lens at different object positions and,
2. how the curvature radius of a converging lens affects the nature of images formed.

To achieve these learning goals, *GO*'s interactive interface provided an avenue for knowledge construction and stimulating learning ground for learners to use their prior knowledge about converging lenses and their personal experiences with lenses in their everyday lives. As can be observed from Figure 4, 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. Based on *GO*'s 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 chosen for intervention, ICTBI2. 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 in order to determine their influence on the nature of images formed at specific object distances. This formed the basis for the second learning goal chosen.

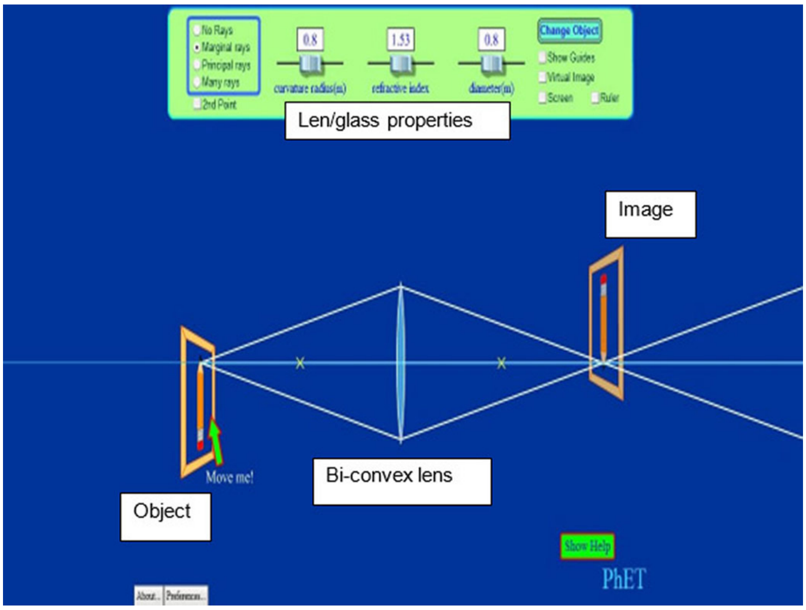


Fig. 4. Unexplored GO PhET simulation environment (taken from http://phet.colorado.edu)

5.2 Interactive learning objective(s) (ILOs)

Owing to the affordances of the PhET simulations, an "interactive learning objective (ILO)" was incorporated in the ICT intervention design in support of the "specific learning objectives" as defined in the physics curriculum. The ILOs feature was purposed to focus on the different ways by which the affordances of a selected PhET simulation could be used to represent the subject matter. Examples of the ILOs feature in the interventions ICTBI1 and ICTBI2 are shown in Figure 5 and Figure 6, respectively.

Interactive learning Objectives	At the end of the lesson, students should be able to use Physics Education technology (PhET) simulation entitled: *waves-on-a-string* guided by exploratory activities on waves, to ▪ observe how energy is transferred when a string is wriggled at one end, ▪ manipulate the various elements of the simulation to identify measurable properties of waves and ▪ compare how the nature of the wave generated changes as one property is varied whilst, others are kept constant.

Fig. 5. Excerpt of the ILOs in the lesson plan document for intervention, ICTBI1 concerning the topic: Wave motion

Interactive learning Objectives	At the end of the lesson, students will be able to use and explore the PhET simulation environment to: ▪ observe how a change in the position of an object placed before a converging lens determines: ➢ the location of the image formed. ➢ the nature of the image formed. ▪ 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.

Fig. 6. Excerpt of ILOs in the lesson plan document for intervention, ICTBI2 concerning the topic: Formation of images by a converging lens

As can be observed from Figure 5 and Figure 6, the ILOs feature in the lesson plan documents shows explicitly how the selected PhET simulation environment was 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 action and directed at projecting an activity-based atmosphere for learners to make meaning of the subject matter. In this capacity, the ILOs feature aimed to provide a suitable platform for teachers to exhibit their ICT-oriented knowledge and pedagogical skills to make the learner the focus in the physics classroom.

5.3 Technological pedagogical content knowledge (TPACK)

TPACK (see Figure 7), as incorporated in the ICT intervention developed in this research, was envisaged to be the "built-in" competency trademark of the teacher in using ICT to create an interactive learner-centered teaching and learning atmosphere in SHS physics classrooms. Figure 7 illustrates how the use of TPACK informed the design of Activity 2 of ICTBI1. As can be inferred from Figure 7, the teacher's "knowledge and understanding of the interplay between content knowledge (CK), pedagogical knowledge (PK) and technology knowledge (TK)" [4] was put to use as the driving force for guiding learners through an exploratory self-directed inquiry in achieving the activity's objective—"To investigate the amplitude property of a wave …" with the *WS* simulation environment.

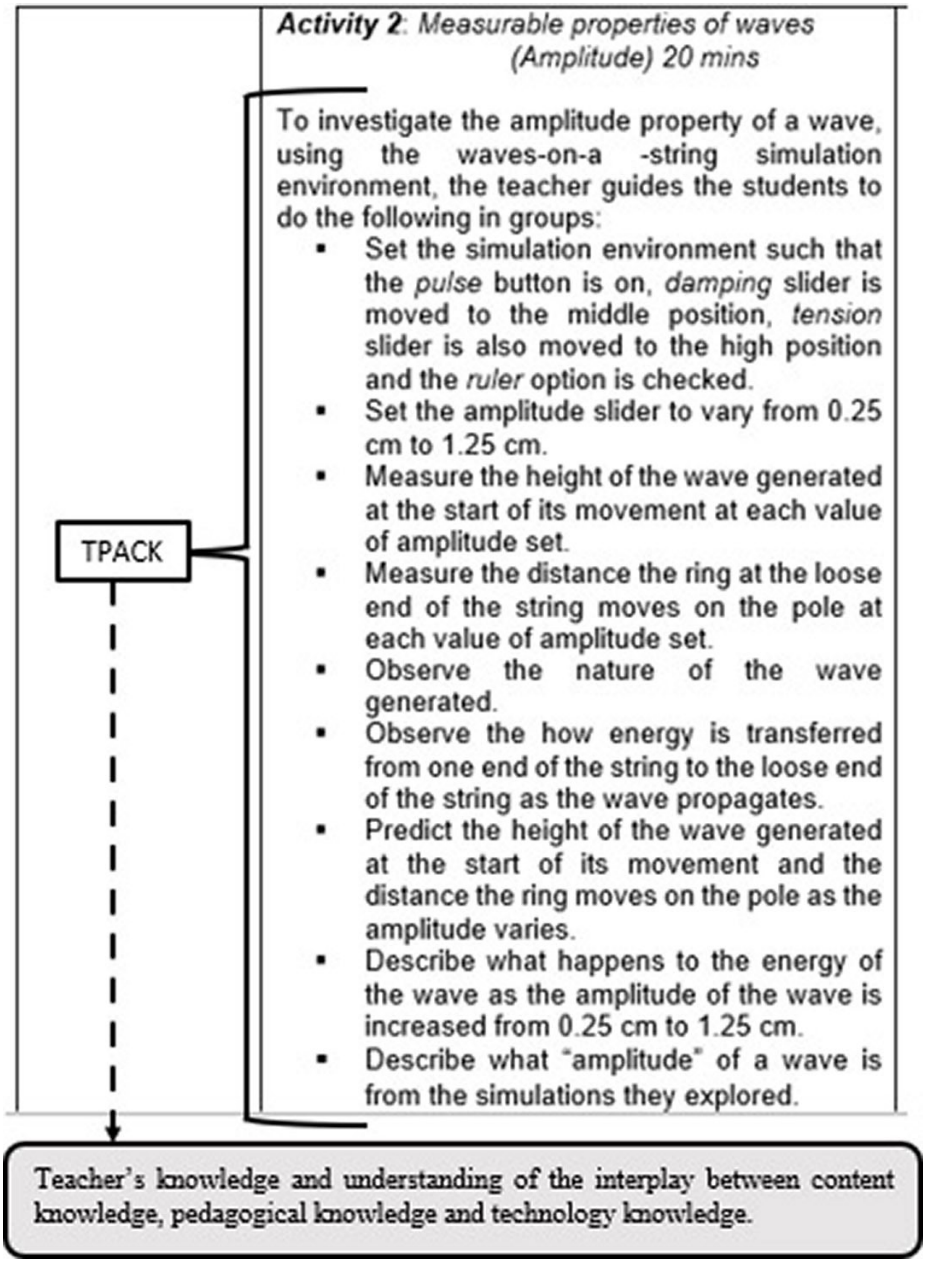


Fig. 7. Illustration of TPACK as applied in the design of activity 2 of ICTBI1

5.4 Five dimensions for meaningful learning with ICT (5DML_ICT) framework

The 5DML-ICT framework was added in the design of the interventions to define the characteristics of interactive teaching in the context of the research. This feature was particularly evident in the lesson activities designed as part of the interventions and incorporated in the design to reflect the active, constructive, authentic, intentional, and cooperative dimensions for meaningful learning as defined in [33]. Figure 8 shows how all the five dimensions were realized in Activity 2 of intervention, ICTBI1.

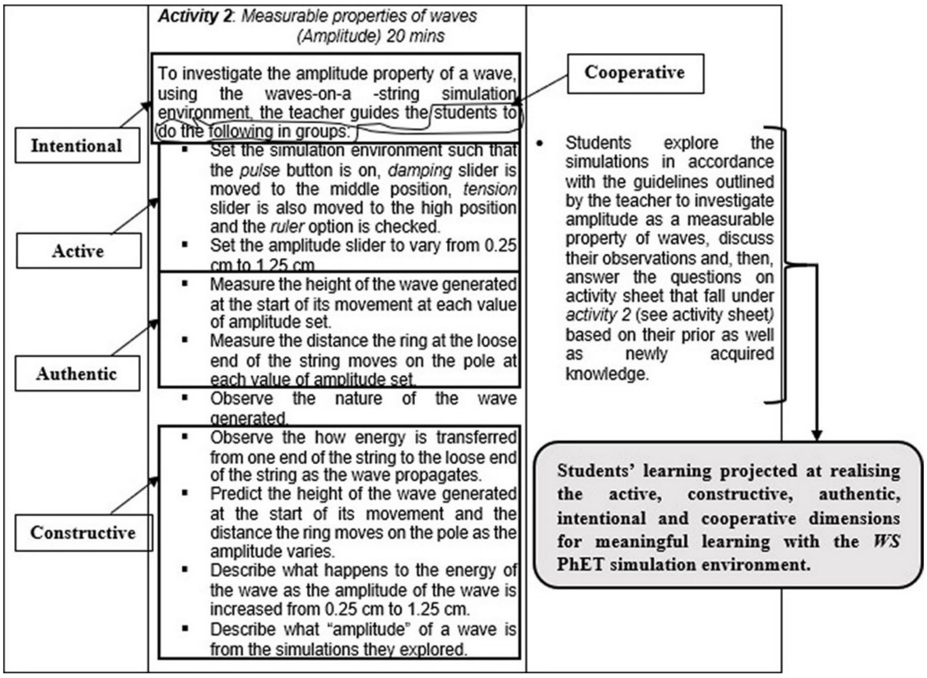


Fig. 8. Illustration of the 5DML-ICT in the design of activity 2 of ICTBI1

5.5 Activity sheet

The ICT intervention also had an activity sheet designed to learn the subject matter with ICT. The addition of the activity sheet was deemed necessary because it provided the means to actively engage learners to take full responsibility for their learning of the subject matter. The activities were designed based on the *WS* and *GO* simulation environments. Two types of inquiry were adopted for the design of the activities—an exploratory self-directed form of inquiry and a demonstrative form of inquiry. With all the two forms of inquiry, ICTBI1 and ICTBI2 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 essential to mention that intervention ICTBI1 was exploratory, emphasizing a Ghanaian classroom situation where both the teacher and students (learners) have access to the computer while ICTBI2 was demonstrative. The demonstrative form of inquiry was considered to provide interventions that reflect the specific context of a Ghanaian SHS physics classroom where only a computer is available to a teacher due to a lack of computer resources. The use of both forms of inquiry in the design of the activities aimed to maximize the potentials of the PhETs to facilitate ownership of the learners through teamwork in order to enhance their understanding of concepts in physics.

The activity sheet comprised three components: introductory activity/activities, main activities, and take-home assignment. 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—this was the case for ICTBI1 (see Figure 9) or in the form of an exploratory activity which was purposed to stimulate learners' discovery of the affordances of the interactive features of the simulation environment by themselves based on their prior knowledge—this was the case for ICTBI2 (see Figure 10).

WAVE MOTION

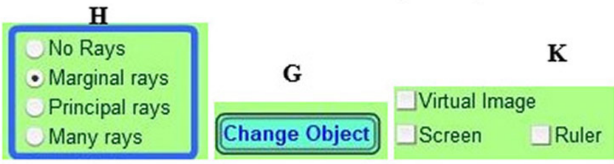
Introductory Activity sheet (pre-test)

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.

Fig. 9. Excerpt of sample introductory activity for ICTBI1

As can be observed from Figure 9, all the test items for the introductory activity (for ICTBI1) were conceptual questions designed to engage learners' previous knowledge about the physics concept: *wave motion*. The introductory (exploratory) activity (for ICTBI2), as shown in Figure 10, 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 explore its features.

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.

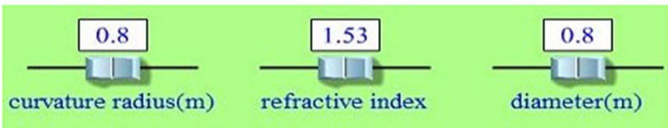


H.………………………………………………………………………………………

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: ………………………………………………………………………

Fig. 10. Excerpt of sample introductory activity for ICTBI2

The main activities for both ICTBI1 and ICTBI2 were designed based on the selected PhETs. These activities were specifically developed to align with the specific learning objectives and the interactive learning objectives chosen. A combination of different types of guidance was used to help learners in their learning with the main activities. These were ensured by using instructions, snapshots from the simulation environment, tables, and follow-up questions. The follow-up question (samples are shown in Figure 11 and Figure 12), in particular, served as a supplement to the various activities that were designed based on the affordances of the *WS* and *GO* simulations. Thus, under every activity considered for the two interventions concerning *Wave motion* and *formation of images by a bi-convex thin lens*, there were guiding (follow-up) questions.

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 behavior 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?

Follow-up questions

Fig. 11. Excerpt of sample activity designed for the ICTBI1 intervention with follow-up questions

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.

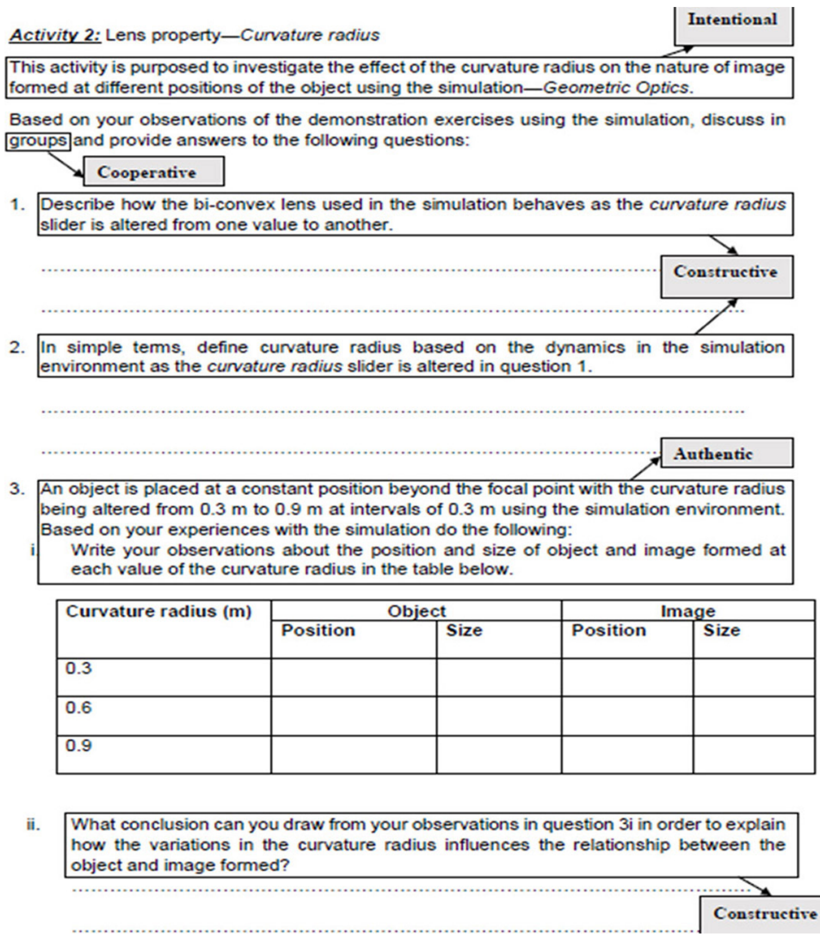
Object position	Image position	Characteristics/nature of imaged formed
Within focal length		
At the focal point		

Follow-up questions

Fig. 12. Excerpt of sample activity designed for the ICTBI2 intervention with follow-up questions

As Figure 11 and Figure 12 depict, the follow-up 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 using the simulation was not for learners to acquire skills on its use only, but also, to help learners achieve their learning goals. The follow-up questions were crucial for facilitating learners' sense-making and observation capabilities and, thus, were designed to provide a platform for them to make candid deductions from the information they had gathered based on their interaction with the simulation environment used in the ICT-based lessons.

The main activities were also designed to project the active, constructive, authentic, intentional, and cooperative dimensions for meaningful learning (see areas marked with rectangular boxes in Figure 13). As adopted from [33], the activities were designed based on the PhETs to engage learners: in learning the subject matter" (i.e., active); to "reflect upon the subject matter and express their ideas and meaning beyond what is presented them" (i.e., constructive); to "connect their personal experiences to the real-world" (i.e., authentic); "in diagnosis, evaluation, and improvement of the learning gap" (intentional); and "in group work for divergent knowledge expressions" (i.e., cooperative). An example of the projection of these dimensions in the ICTBI2 intervention is shown in Figure 13.



Curvature radius (m)	Object		Image	
	Position	Size	Position	Size
0.3				
0.6				
0.9				

Fig. 13. Illustration of the five dimensions as projected in activity 2 of ICTBI2

The evidence provided so far concerning the activity sheet element of the ICT intervention highlight that the activity sheet element was incorporated in the design of the interventions to provide an interactive avenue for learners to make a connection between their prior knowledge, the interactive elements of the simulation interface and the physics concepts of interest to facilitate meaningful learning.

5.6 Collaborative classroom arrangement (CCA)

This feature formed the basis for all classroom arrangements and was included to promote divergent knowledge expressions with the two ICT-based interventions. All activities designed on the activity sheet were geared towards encouraging teamwork among learners to learn the subject matter using PhETs and provide a platform for discussions as learners explore the simulation environment to discover its potentials. Also, using the CCA feature, the cooperative dimension of the 5DML_ICT framework was put into action to encourage learners to share ideas about the physics concepts among themselves and enforce teamwork capabilities in them.

Based on all the features discussed herein, this research advocates the two interventions (i.e., ICTBI1 and ICTBI2) designed herein to fit the realities of the Ghanaian SHS classroom in a manner that makes the teaching of physics interactive.

6 Discussion

The main goal of this research was to determine the features of an ICT-based intervention that best fits the realities in the Ghanaian SHS classroom. Informed by the literature [4], [33], [16], [19], [20], [21], [22], [23], [24], [26], [27] reviewed, the features that governed the design of the ICT-based intervention and, thus, were deemed fit for the Ghanaian SHS physics classroom context included: a) a readily available, sustainable, context- and content-specific ICT teaching and learning environment (e.g., PhETs); b) an ICT-oriented knowledge base for teachers' uptake of ICT (e.g., TPACK); c) an underlining framework for interactive and learner-centred teaching approach with ICT (e.g., 5DML_ICT framework); d) ICT-driven interactive lesson objectives; e) an inquiry-driven, activity- and ICT-based learning material (e.g., activity sheet); and f) a collaborative classroom arrangement.

The affordances of both the *WS* (see Figure 2) and *GO* (see Figure 4) simulations situate PhETs as an interactive ICT resource for supporting interactive and learner-centered teaching and meaningful learning outcomes. Hence, the PhETs were considered essential for designing an ICT intervention that fits the Ghanaian SHS physics classroom. Guided by Rehn et al.'s [16] definition of targeted simulations—"… stand-alone simulations designed to cover a particular topic in a scientific discipline", the interactive nature of the PhETs as observed in this research, perhaps, identifies PhETs as 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 enhanced learning outcomes [23]. Furthermore, the interactive interfaces of both the *WS* and *GO* PhETs as highlighted in the results section project the PhETs to possess the needed potentials for stimulating students' interest in physics as a subject and also, providing an authentic platform for students to think critically as well as gain in-depth understanding of abstract concepts in physics [24]. As situated in the literature, these ideas were instrumental to the design and development of the interventions. This is because they served as essential building blocks for knowledge construction and motivation for learning the subject matter through a demonstrative, exploratory, and discovery form of inquiry.

The interactive learning objectives feature (see Figure 5 and Figure 6) in the intervention was found on the basis that learning as a process is not without the participation and active interaction [4], [19]. The inclusion of the ILOs features in support of the specific learning objectives was necessary to ensure that instructional, and learning processes occur in an atmosphere that is highly driven by interactions, reflections, and learners' personal experiences with ICT and not in a teacher-centered setting. Hence, the ILOs feature appears to bring to bear the concept of interactivity in the physics classroom.

Guided by Mishra and Koehler's [20] TPACK framework and Howland et al.'s [21] concept of "Five dimensions for meaningful learning with ICT" as defined in [33], TPACK and the 5DML_ICT framework (see Figure 7 and Figure 8, respectively) were initiated in the design of the interventions for the sole purpose of bringing into practice how interactive teaching with ICT could be realized and driven by teachers' specific ICT-oriented knowledge (TPACK) for the creation of an interactive and learner-focused classroom for meaningful learning outcomes. Thus, TPACK seems to inspire Voogt and McKenney's [22] proposition that TPACK is the conceptual base to consider for studying the kind of knowledge teachers require to use technology to teach.

The use of the activity sheet (see Figure 9, Figure 10, Figure 11, Figure 12 and Figure 13) as a form of learning material in the intervention design as reported, was informed by the assertion that "students must be active during learning" [4] for enhanced learning outcomes. Thus, the activity sheet as incorporated in the intervention, perhaps, reflects various ways in which interactivity, as defined by the use of the active, constructive, intentional, authentic, and cooperative dimensions [33], [21] could be realized in order to motivate the learner to take full responsibility of the learning process as well as stimulate and also, sustain their interest throughout the instructional process with ICT.

Vygotsky's [27] idea of social constructivism adds a collaborative dimension to the instructional process. Consequently, as emphasized earlier in the results section, the CCA feature was intended to facilitate the creation of a friendly environment for learners to learn from each other. In particular, it was incorporated to enable learners to appreciate different ways of seeing the world and foster their understanding of concepts that they would not understand on their own under normal circumstances. In this regard, the CCA feature of the intervention emphasizes the benefits of social interactions in the classroom in light of Jonassen et al.'s description of the cooperative attribute of meaningful learning—"collaboration propelled by conversations" [26].

Based on the research results, we propose using ICT-based interventions with features such as that discussed in this research as exemplary curriculum material for teacher training and professional development programs for integrating ICT into physics teaching. Such an initiative will provide pre-service and practicing teachers with authentic examples of how to effectively using ICT (e.g., PhETs) in their teaching practices. It will also serve as a model to guide teachers in designing their ICT-based lesson artifacts and inform their understanding of what ICT-based innovations constitute.

That notwithstanding, careful measures should be taken to ensure that teachers have an adequate understanding of the design process informed by theory to avoid replicating the excellent material. This could prevent them from being creative in the design and development of their ICT-supported lessons.

The study results also speak to the importance of providing theoretical and conceptual bases for inspiring teachers' competencies in using ICT to teach interactively. In light of this, the study advocates considering theoretical frameworks for ICT integration as essential ingredients for equipping teachers with the needed ICT-oriented knowledge and skills that are not technocentric but theory-induced and content-focused.

In as much as this research was conducted following existing literature guidelines on systematic review processes, the possibility of missing out on relevant published articles was inevitable. To address this issue, technical reports and conference proceedings were scanned for relevant information based on recommendations by Kitchenham [34].

7 Conclusion

The present research was purposed to determine the features of an ICT-based intervention that fits the realities in the Ghanaian SHS physics classroom context and advances the prospects of interactive teaching with ICT. Utilizing a systematic review of extant literature, this research identified an intervention with inherent features that encompass: a readily available, sustainable, context- and content-specific ICT teaching and learning environment such as PhET simulation environment; an ICT-oriented knowledge base for teachers' uptake of ICT such as TPACK; an underlining framework for defining interactive learner-centered teaching approach with ICT such as 5DML_ICT framework; ICT-driven interactive lesson objectives; an inquiry-driven, activity- and ICT-based learning material such as activity sheet; and a collaborative classroom arrangement, as fit for facilitating interactive teaching in the Ghanaian SHS physics classroom. By drawing on literature, each intervention feature, as discussed herein, was carefully chosen and incorporated to promote interactive teaching uniquely. These inherent features seemingly position the intervention as an essential means by which both pre-service and practicing teachers could be inspired to gain a deeper understanding of ICT-based innovations to develop competencies for integrating ICT into their teaching practices in an interactive manner [41–43]. While it can be said that perhaps, the intervention possesses the appropriate features that are sensitive to the needs of the Ghanaian senior high school classroom, the same statement may not be accurate for other countries in that these features as identified in this research may not apply to their classroom contexts, which could differ. Nevertheless, it is encouraging to mention that the intervention is essential and could be adapted to incorporate features that meet other contexts' specific needs, especially in Sub-Saharan Africa.

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