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*Research article*

# DiGIBST: An inquiry-based digital game-based learning pedagogical model for science teaching

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**Abstract:** This research aims to propose a pedagogical model that structures the implementation of digital game-based learning (DGBL) in science classes. Design-based research guided the design, development, implementation, and redesign processes of the prototype pedagogical model. The principles that informed the design of the model were gleaned from empirical data on DGBL conditions in junior high schools and science teachers' DGBL practices and perceived barriers to implementing DGBL. Curriculum and science education experts reviewed the model and found it usable, adoptable, implementable, and appropriate for junior high school science classes. The lesson designed based on the model improved junior high school students' motivation to learn and achievement in science. Likewise, science teachers perceived the pedagogical model to be easy to use, useful in science teaching, beneficial for students, and able to enhance their teaching efficiency and productivity. This study is the first to propose a DGBL pedagogical model for science.

**Keywords:** digital games, digital game-based learning, digital game-based learning in science, science teachers' DGBL practices, DGBL pedagogical model

## 1. Introduction

The integration of digital games such as serious games in science, technology, engineering, and mathematics (STEM) education significantly improves learning gains [1]. These games enhance the learning of scientific content [2–10] and facilitate the acquisition of 21st-century skills such as decision-making [11], flexibility, critical thinking, creativity, self-regulation [12], collaboration skills and problem-solving [12,13], and inventive thinking [14]. Likewise, they promote social development [15] and foster collaborative and cooperation skills [16]. Indeed, serious games deserve a place in science classrooms.

However, the perceived efficacy of serious games does not result in their widespread integration in science teaching or in an increase in teachers' competence in implementing digital game-based learning (DGBL) in science. As identified by [17], the reasons for the non-adoption of serious games by teachers are the unsupportive school conditions and unclear pedagogical roles played by teachers in digital game-based learning. To address the barriers to DGBL adoption, the authors of [18] and [19] posited that teachers who wish to integrate serious games into the curriculum need to be empowered. The authors of [20] and [21] further argued that a pedagogical model would help teachers effectively implement digital game-based learning. Pedagogical models describe the roles of both teachers and students in DGBL and provide a structure for its implementation [22]. They guide teachers who will use serious games according to their teaching contexts [23].

Pedagogical models and frameworks guiding the process of DGBL exist. For instance, Garris et al. [24] developed an input-process-output model for instructional games, highlighting the critical features of games that are of interest from an instructional perspective. The model discussed the game cycle of user judgments, behavior, and feedback and the types of learning outcomes that a particular game can achieve. Meanwhile, Kangas [22] proposed a pedagogical model of creative and playful learning for designing game-based teaching and learning, which identified the crucial roles of the teacher in implementing DGBL. Foster and Shah [17] offered a play-based model called play curricular activity reflection discussion (PCaRD) to help teachers integrate games in classrooms. The model helps teachers incorporate games into the curriculum. It suggests that all activities should be anchored on the game as it empowers a teacher to connect DGBL to the curriculum.

Additionally, Echeverria et al. [25] developed a framework that guides the design of educational games and their integration in the classroom. The framework provides a step-by-step design process for defining the elements of a game in accordance with the educational and pedagogical needs established by the user. They claimed to have used a "pedagogical model" called CMPG that guides teachers in using games in the classroom. On the other hand, Watson and Fang [26] proposed a simplified model that uses PBL as a framework for implementing video games in school settings. As expected, this framework only includes PBL processes and does not consider game elements and characteristics. Bidarra et al. [27] proposed a model called AIDLET, which provides a set of questions that may guide the selection of games. As shown, the existing frameworks and models on DGBL are either too generic or inadequate. To date, not a single pedagogical model has been proposed to guide the integration of serious games in science education or the implementation of DGBL in science classes.

### 1.1. Digital game-based learning

Digital game-based learning is a pedagogical approach that integrates digital games such as serious games into the curriculum [28]. Erhel and Jamet [29] described DGBL as "a competitive activity in which students are given educational goals intended to promote knowledge acquisition”. It uses digital games such as serious games to foster learning [30] and attain specific learning outcomes [31].

The effectiveness of DGBL as an approach has been established in the literature. For instance, Wouters et al. [32] found that serious games were more effective than traditional modes of instruction and yielded better retention. On the effect of digital games on learning, particularly in K-16 students, Clark [33] reported that digital games significantly improved learning compared to non-game conditions in terms of media comparisons. Similarly, on the use of serious games in education, particularly for the period 2009–2018, Zhonggen [34] underscored that the number of studies showing that serious games positively affect learning is overwhelming, with only a few studies reporting negative results. Among the major findings highlighted was that games improved students’ performance in science, facilitated the acquisition of science concepts, and prolonged the retention of scientific knowledge. It was also found that, in general, digital game-based learning is more effective than non-game conditions.

### 1.2. Learning science through DGBL

Learning in DGBL occurs when the playing of a computer game causes a change in students’ academic knowledge or enhancement in cognitive skills [35]. DGBL influences learning by modifying cognitive processes and affecting motivation [32]. It is in this sense that computer games help communicate abstract science concepts [3]. When communicated effectively, multimedia representations such as video games help students visualize complex science concepts. The “multisensory information representation in computer games facilitates schema construction by offering a learner a ready-made explicit representation of a complicated concept” [36].

The effect of the utilization of computer games such as serious games in science is well-documented. Wrzesien and Raya [10] introduced a serious virtual world (SVW) and reported a significant difference between pre- and post-knowledge test scores in natural science and ecology. Klisch et al. [6] reported that in playing the science game Uncommon Scents, students demonstrated significant science content knowledge, as evidenced by the improvement in their pre-test to post-test scores. Marino et al. [37] used beta versions of You Make Me Sick! and Prisoner of Echo, and results showed that students enjoyed learning science through video games. Meluso et al. [8] introduced the 3D intelligent learning environment called Crystal Island and investigated its effects on fifth graders’ science content learning and science self-efficacy. Results showed that regardless of gameplay modes, students demonstrated an increase in self-efficacy and content knowledge in science. Furthermore, Anderson and Barnett [2] explored the impact of using a 3D simulation game called Supercharged! on Grade 8 students’ understanding of electrostatics. Designed based on the laws of electrostatics, students in the experimental group were able to give more elaborate descriptions of electric fields than those in the control group. In addition, Annetta et al. [4] developed a game called STIMULATE (Science Training Immersive Modules for University Learning Around Teacher Education) and reported that the game successfully improved pre-service teachers’ understanding of safety in a science classroom and laboratory setting.

## 2. Methodology

### 2.1. Study phases

The present study consists of two phases. Phase 1 includes the needs assessment, development of the prototype, and expert review. The needs assessment allowed us to gather data on the conditions of the junior high schools on various DGBL parameters and science teachers' effective DGBL practices, which later served as a basis for generating design principles for the pedagogical model. The expert review was done by experts on science education, the K to 12 science curriculum, and educational technology. Phase 2 is field evaluation. Field evaluation, or tryout, means implementing the pedagogical model in the setting for which it was designed. In this study, the tryout was done by designing a lesson based on the model and implementing said lesson in a Grade 8 science class.

### 2.2. Research participants

The participants of Phase 1 were 293 science teachers and 1075 students in Grade 7 to Grade 10 of public junior high schools in Northern Mindanao, Philippines and five experts from various universities in the Philippines. Phase 2 of the study involved 68 junior high school students and their science teacher.

### 2.3. Measures

**Teacher survey questionnaire (TSQ).** This four-part questionnaire comprises multiple-choice, short-answer, Yes-No, True-False, and open-ended questions. It was used to collect data on the conditions of schools on the various DGBL parameters and science teachers' engagement and knowledge of serious games and DGBL.

**Semi-structured interview/focus group discussion guide.** This consists of 12 questions asked during the interviews and focus group discussions (FGDs) with science teachers. Interviews and FGDs were conducted among teachers who claim to have utilized digital games in their science classes based on their responses in the TSQ. These approaches did not only confirm teachers' responses in the survey questionnaire but also gathered their practices in implementing DGBL. Interviews were done if only one teacher claimed to have utilized digital games in a school. FGDs, on the other hand, were conducted in schools wherein at least three teachers claimed to have utilized digital games in their science classes.

**Student survey questionnaire (SSQ).** A combination of Yes-No, open-ended, and short-answer questions, consisting of two parts, namely students' profile and gaming experience. It gathered information on students' engagement with games either in class or outside of school. The information from this instrument validated the responses generated by the TSQ.

**Science motivation questionnaire (SMQ).** This is a 20-item rating scale measuring students' motivation to learn science before and after the implementation of the game-based lesson. This was adopted from S. M. Glynn's Science Motivation Questionnaire – II [38]. The items were modified for the target respondents.

**Achievement test.** This is a 15-item multiple-choice test developed by the teacher-implementer (science teacher of the tryout class) to measure students' conceptual understanding of the in-game science topic (projectile motion) before and after the tryout.

### 2.4. Data collection procedure and analysis

The study utilized design-based research (DBR) methodology. DBR is a "methodology designed by and for educators that seek to increase the impact, transfer, and translation of education research into improved practice and highlights the need to build theories and design principles which are expected to guide, inform, and enhance both practice and research in educational contexts" [39]. DGBL pedagogical models such as the Play Curricular Activity Reflection Discussion (PCaRD) of [40], as cited by [17] was created using DBR methodology.

To develop the pedagogical model, the conditions of junior high schools on various DGBL parameters were gathered using the TSQ and SSQ. The science teachers' DGBL practices were gathered through interviews and focus group discussions. Using the needs assessment data, design principles were generated. In DBR, design principles are statements or heuristics that serve as a guide in designing the prototype pedagogical model's components. The needs assessment data were placed side-by-side with the learning principles of good video games [41], interaction cycle for games [42], and elements of game design for learning [43]. The principles and DGBL practices supported by the existing frameworks on DGBL and serious games were adopted as design principles. The design principles were further articulated into actual design and implementation strategies [44]. The design and implementation strategies described how each design principle was implemented in the prototype pedagogical model.

The prototype was submitted for field evaluation. Field evaluation as an external validation method means using the prototype to produce instruction [45]. Trying out the pedagogical model means implementing it in the setting for which it was designed, in this case in the context of junior high school science classes. The tryout was conducted in any level of these classes. The field evaluation or tryout of the prototype was done in a junior high school whose students were already comfortable with the distance learning setup. The tryout utilized the non-equivalent control group pre-test–post-test quasi-experimental design. Two sections of Grade 8 were chosen—one as the treatment group (33 students) and the other as the control group (35 students). The two classes were handled by the same teacher and had the same level of cognitive ability (no significant difference in terms of scores in the last four quizzes, $p = .822$). The teacher implemented a PhET (physics education technology)-based lesson on projectile motion in the control group. A lesson on the same topic but designed based on the developed prototype (or game-based lesson) was given to the treatment group. The students in the treatment group played Tanks 2 while those in the control group manipulated a popular PhET simulation on projectile motion. Students' motivation to learn science and achievement were measured before and after the experiment. The experiment lasted for two days. A focus group discussion with selected students in the treatment group was conducted a day after the lesson implementation. The prototype pedagogical model was revised after the tryout.

The quantitative survey data were analyzed using measures of central tendency and presented in percentages. The FGD and interview data were transcribed, translated, and presented in themes to bring out the DGBL practices of junior high school science teachers. The scores of the students in the different questionnaires administered during the tryout were analyzed using both parametric and non-parametric tests. Independent samples t-test was used in datasets that were normally distributed and without outliers. Otherwise, the Mann-Whitney U test was used.

## 3. Results

### 3.1. Sources of information for the pedagogical model

The DGBL conditions of junior high schools and the effective DGBL practices of science teachers informed the design of the pedagogical model. The results of the survey revealed that the majority of the sample schools had the infrastructure for DGBL. The majority (96.9%) had Information and Communication Technologies (ICT) or computer laboratories which, on average, had 50 functional computer units connected to the Internet. The data also confirmed that the majority (80.7%) of junior high school students played video games. However, the students reported that teachers rarely used serious games in science classes. The result is consistent with the data from the TSQ that only 18.4% (54 out of 293) of science teachers use serious games. The games played are mostly free and categorized into casual puzzles, simulations, racing, and platform games. The majority of serious games are used during proper lessons. It was also found that most of the science teachers had limited understanding and awareness of DGBL and schools did not have a clear-cut policy regarding the use of either serious games or DGBL. As a result, the implementation of DGBL varied from school to school.

The FGD and interview data further showed that although unstructured, science teachers were implementing DGBL in their classes. The DGBL practices of science teachers fall into one of the following themes, namely: using games as motivational tools (e.g., “I use simulations to enhance the students, to sustain their interest”), integrating serious games into the lesson (e.g., “I placed the game in the motivation part of the lesson, in the engagement part”), designing the DGBL activities (e.g., “I designed the activity sheet based on the game”), structuring the DGBL class (e.g., “I allow students to play Crayon Deluxe even before I discuss Torque”, managing the DGBL class (e.g., “The play session is one hour; I grouped them and I distributed the activity sheets then the game started”), and giving assessment and feedback (e.g., “I only evaluated the analysis level of students”).

The needs assessment data generated the design principles for the pedagogical model. Sixteen principles were formulated that informed the design of the prototype, namely: 1) The pedagogical model needs to enhance science teachers’ awareness of DGBL and serious games; 2) there is a need to emphasize the role of policy in the success of DGBL implementation; 3) successful DGBL implementation requires DGBL TPACK (technological, pedagogical, and content knowledge); 4) student activities, support materials, and corresponding assessment tools are designed based on the game; 5) levels and scores inform student progress in the game; hence, they must be recorded; 6) incentives and rewards increase interaction with the game and encourage students to play more; 7) exploring the game before the actual play invites a player to immerse themselves into the game world; 8) students must understand the goal of the game, instructional content, objectives, rules, and goals of each task; 9) the teacher provides a brief tutorial to show the game interface and controls; 10) learning of a science topic is the primary goal of DGBL and must address the competencies/standards set for the topic in the curriculum; 11) DGBL fosters authentic learning; 12) simulation games may be used to stimulate students’ interest on a topic or enrich students’ understanding about a topic; 13) games are not only used as motivational tools but as lesson themselves that promote problem solving and critical thinking; 14) a good storyline is a primary consideration in choosing a game; 15) facilitation and monitoring are required during gameplay; and 16) the class discussion comes after gameplay, giving an opportunity for students to share what they learned about the in-game topic and reflect on their gaming experience. The first three design principles are based on the DGBL conditions of sample schools in implementing DGBL in science, while the rest (4–16) are obtained from the effective DGBL practices of science teachers.

### 3.2. The developed pedagogical model

The prototype pedagogical model is called DiGIBST, which stands for digital game-based learning for inquiry-based science teaching. The model went through two iteration cycles. The first version is shown in Figure 1. As shown, the pedagogical model supports the goal of the K to 12 science curriculum [46], which is to develop scientific and technological literacy among students. This goal may be achieved through the adoption and implementation of inquiry-based science using the four phases of digital game-based learning instruction identified in the DiGIBST pedagogical model: (1) orient and demo, (2) explore, (3) guided play, and (4) debrief and assess. In addition, the DiGIBST pedagogical model recognizes DGBL policy and teachers' DGBL TPACK as key drivers of successful DGBL instruction in junior high school science.

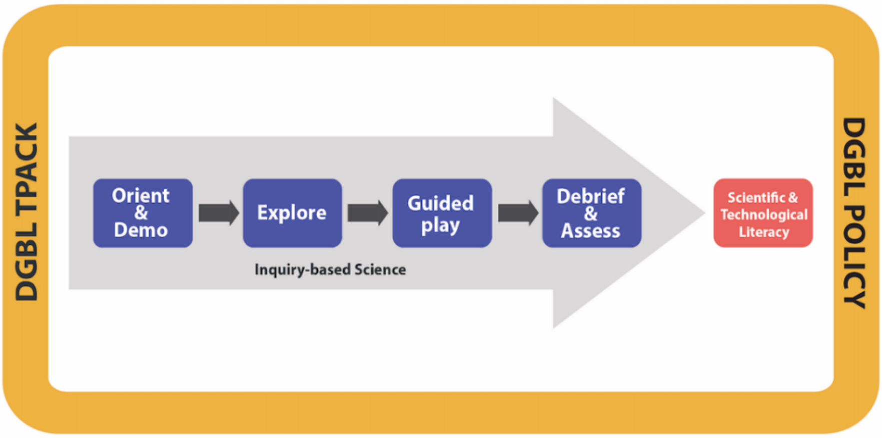

**Figure 1.** The first version of the DiGIBST pedagogical model.

The prototype emphasizes the need to develop DGBL TPACK amongst junior high school science teachers. The TPACK framework, proposed by [47], informs teachers about introducing technology (e.g., serious games) in the classroom. It has three overlapping areas of knowledge: technological content knowledge (TCK), technological pedagogical knowledge (TPK), and pedagogical content knowledge (PCK). In the context of DGBL, TCK would help the teachers identify science topics and their corresponding serious games. On the other hand, TPK would guide teachers in implementing DGBL and would ensure that the serious game being used is effective for game-based learning. Meanwhile, PCK would provide teachers with the knowledge to use DGBL strategies that foster the learning of a science topic. In the assumption that serious games are utilized by content area teachers who are supported by appropriate pedagogical practices and technologies in order to meet desired learning outcomes, the convergence of the three overlapping areas of knowledge, which are TCK, TPK, and PCK, may be considered as DGBL TPACK [48].

The needs assessment data show that the majority of sample schools have no written policy on DGBL or, at the very least, on the use of video games and serious games in the classroom. For this reason, DGBL policy is included in the prototype to highlight its importance. With a clear-cut policy in place, schools could properly manage their DGBL infrastructure, such as ICT/computer laboratories. It was found from the survey that 96.9% of the sample schools had ICT or computer laboratories, and each school had an average of 50 functional computer units, yet these were not maximized for DGBL.

Furthermore, Figure 1 indicates that the ultimate outcome of digital game-based learning is to produce scientifically and technologically literate students, which is also the goal of the K to 12 science curriculum. Scientific literacy includes (but is not limited to) the knowledge about scientific facts, concepts, and processes manifested in how a person evaluates information or solves a real-world problem [49]. On the other hand, technological literacy is “the ability to use, manage, evaluate, and understand technology” [50]. The development of scientific and technological literacy through digital game-based learning is made possible through the use of serious games in science. Generally, serious games are video games that are effectively used in training to acquire a target skill [51]. As previously stated, serious science games that are specially made for science instruction promote the learning of important 21st-century skills and the learning of science content.

The prototype is anchored on inquiry-based science. Scientific inquiry “requires the use of evidence, logic, and imagination in developing explanations about the natural world” [52]. Students will only have the opportunity to ask questions, investigate and find solutions to a problem, and propose evidence-based results if the approach is inquiry-based. It was revealed during the interviews and focused group discussions that most science teachers had been implementing inquiry-based learning using either the 5E or 7E instructional model. As such, the DiGIBST pedagogical model utilized inquiry-based science as the backbone of DGBL instruction.

The first phase of DGBL instruction is giving a brief orientation to students about the serious game that will be used in class. As practiced, science teachers made sure that students understood the essential game elements: instructional content, objectives, rules, and goals of each task. Details, such as how to win the game, finish within the allotted time, and obtain a high score, must be made clear to them [42]. After introducing the game, it was necessary to show the game to the class because some science teachers believed (as shown in the needs assessment data) that DGBL instruction would be more successful if all students were familiar with the game interface before allowing them to play. Even if the majority (80.7%) of the students were into playing computer/mobile games outside of school, there were still non-gamers. Another effective practice of science teachers in implementing DGBL is providing students with a brief tutorial on the game to show the game interface and controls. During the demo, the teacher may show the game controls and navigation buttons, but not how the game is played, as students will be learning it in the succeeding phases. The teacher must also highlight the objective of the game or the problem that students need to explore and solve.

After acquiring relevant information about the game, students open the serious game from their assigned computers. Then, they are given some time to take a quick look at the game world before actual play, mainly to explore the features, controls, and buttons mentioned during the orientation. Through this, students may develop a holistic understanding of the game world and not just see unrelated events and actions [41]. During this phase, students may also start thinking about the problem situation/mission/task that they need to work on. Exploring the game invites learners to analyze a problem, formulate a hypothesis, generate solutions, and make decisions [26].

Guided play comes after the exploration phase. Students play a serious game to complete a task/mission or solve a problem. The teacher makes sure that students can focus on their play so that they can successfully inherit a role or identity within the game. Otherwise, deep learning may not occur [41].

The last phase of DGBL instruction called debrief and assess follows the actual play. Effective game-based learning requires debriefing [26]. The students share their overall impression of the serious game, the things they like most about the game, and those they want to improve in the game and the DGBL session. Also, the teacher may ask the players who got the highest and the lowest scores in the game to talk about their experiences, particularly how they won and why they lost. In doing this, DGBL provides an avenue for students to learn from each other and rely on each other's skills and expertise [41]. In this phase, the class also talks about the in-game science topic. The objectives of the lesson in relation to the topic and the serious game are tackled in a teacher-led discussion. One effective practice for this phase is finding the real-life applications of an in-game science topic. This phase concludes with the giving of appropriate assessment, which according to [24], is an important aspect of the game cycle.

### 3.3. Validation of the prototype pedagogical model

The developed prototype went through a series of formative evaluations. The expert review confirmed that the prototype pedagogical model is clearly framed, its parts and sections are appropriate, can be adopted by its target users, and is easy to administer or implement. The comments and suggestions of the curriculum and science education experts were implemented, and the prototype was tried out in a Grade 8 science class. The results of the tryout are summarized in Table 1 and Table 2. As shown in Table 1, the treatment group (mean rank = 21.61) had a slightly higher mean rank than the control group (mean rank = 20.29). However, a Mann-Whitney test indicates that the slight difference in their average ranks is not statistically significant (U = 195.500, p = .724). The result implies that the game-based lesson and the PhET-based lesson provided approximately the same level of interest or motivation toward science learning to students in both treatment and control groups. In this study, the PhET-based lesson and the lesson designed based on the DiGIBST pedagogical model generated almost the same magnitude of motivational gains for Grade 8 students.

**Table 1.** Difference between control and treatment groups' post-motivation to learn science.

| Control group | | Treatment group | | *U* | *p* |
|---|---|---|---|---|---|
| *n* | Mean rank | *n* | Mean rank | | |
| 19 | 20.29 | 22 | 21.61 | 195. 500 | .724 |

The control and treatment groups' post-achievement test scores are presented in Table 2. Independent samples t-test reveals that the difference between the control and treatment groups' post-test scores is not statistically significant [t(47) = -1.669, p = 0.102]. The non-significant result suggests that the intervention (game-based lesson) is as effective as the positive control (PhET-based lesson). It also implies that the PhET-based lesson and the lesson designed based on the pedagogical model effected the same amount of conceptual change upon students of both groups.

**Table 2.** Difference between control and treatment groups' post-achievement test scores.

| Control group | | | Treatment group | | | t(47) | *p* |
|---|---|---|---|---|---|---|---|
| *n* | M | SD | *n* | M | SD | | |
| 23 | 7.7391 | 3.12202 | 26 | 6.3077 | 2.88124 | -1.669 | 0.102 |

Eight students from the tryout class were invited to a focus group discussion. The students remarked that the lesson was pretty normal except that there was a game, and the lesson was based on the game. They also found their most recent class to be more interactive than their usual physics classes; it was fun, engaging, exciting, lively, interesting, encouraged participation, and motivated them to attend class. The students also found the lesson to be a new technique in teaching, which facilitated the learning of a science topic. Compared to the control group, the tryout class was noticeably livelier. Conceptual questions were asked during the discussion in both classes, but students in the tryout class were more responsive to the questions, which were contextualized on the game. According to the students, unresponsiveness or seemingly passive behavior during class discussion is typical in their daily physics class. It was only during the implementation of the game-based lesson that students were actively participating.

## 4. Discussion and conclusions

The DiGIBST pedagogical model, which describes how science teachers could effectively use DGBL science teaching, is both theory- and practice-based. The design-based research methodology adopted in the study generated design principles from junior high schools' DGBL conditions and science teachers' effective DGBL practices.

The results of the tryout indicated that both the game-based and PhET-based lessons have positive effects on students' motivation towards learning science. The result is unsurprising considering that the effectiveness of DGBL is well-established in various studies [34,37]. PhET, on the other hand, is reported to have a positive effect on students' motivation [53,54]. While the game-based lesson was designed based on a research-based pedagogical model, the PhET simulation on projectile motion was likewise research-based, extensively tested and evaluated for educational effectiveness [55], and used by teachers primarily to develop enjoyment or students' interest in science [56]. Also, both lessons integrate a game—a video game in the game-based lesson and a game-like simulation in PhET; as [57] puts it, playing digital games in general has a positive influence on motivation, and the motivation for playing games often result in a motivation for learning. Games "stimulate curiosity and interest by presenting learning activities in meaningful contexts in which the learner is in control" [58]. "Simulations and games have the potential to advance multiple science learning goals, including motivation to learn science" [59].

The results revealed that the game-based and PhET-based lessons improved students' conceptual understanding of projectile motion. The ability of DGBL to improve achievements in science has been established in various studies [e.g., 10, 6, 37, 8, 13, 4]. Similarly, the use of PhET simulations facilitates the learning of science concepts [53,60]. In general, serious games and simulations help students learn science by providing straightforward visualizations of science concepts and phenomena. They are comprehensible models that help learners relate abstract representations of a concept to the real world [59]. The authors of [59], through the Committee on Science Learning:

Computer Games, Simulations, and Education, further admitted that there are existing pieces of evidence proving that educational video games and computer simulations enhance conceptual understanding.

Additionally, the results of the tryout provided adequate information that led to the finalization of the DiGIBST pedagogical model (see Figure 2).

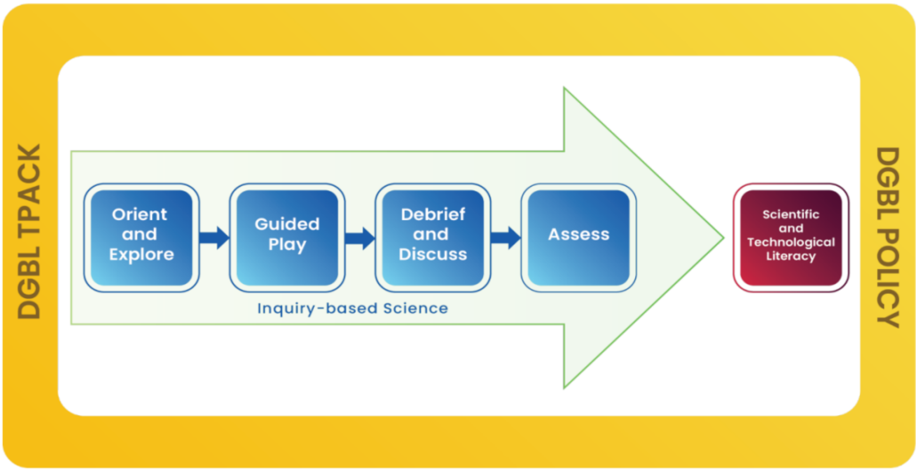

**Figure 2**. The final DiGIBST pedagogical model.

The original design principles were revised and, consequently, so was the prototype. The final version of the pedagogical model still comprised four phases but with some modifications on the phases: Orient and Explore, Guided Play, Debrief and Discuss, and Assess. It was found during the tryout that demonstration was no longer necessary. The students felt that the tutorial given during the Orient phase was enough to familiarize them with the game controls and navigation buttons. Hence, the term “Demo” was removed from “Orient and Demo” and the revised phase is called “Orient and Explore,” merging the tutorial, orientation, and exploration of the game into one phase. From being subsumed under “Debrief”, “Discuss” was spelled out to highlight the importance of the discussion of the in-game science topic in DGBL instruction. The new phase was called “Debrief and Discuss”. Assess was set out as a separate, final phase of DGBL instruction in DiGIBST.

Overall, this study filled in significant gaps in digital game-based learning research. The DiGIBST pedagogical model clarifies the pedagogical roles of science teachers in DGBL and guides the implementation of DGBL in junior high school science classes. To reiterate, our results suggest that, like the time-tested approaches in science teaching, digital game-based learning through the use of the DiGIBST pedagogical model can improve junior high school students’ achievements and motivation in science.

## 5. Limitations

The lesson designed based on the prototype pedagogical model was implemented only in one class. Implementing it in at least five randomly selected junior high schools could have yielded an interestingly different result. Second, the study failed to establish whether the identified drivers of successful DGBL implementation, such as DGBL policy and DGBL TPACK, affect the implementation of the DiGIBST pedagogical model. Data from the pilot implementation of the pedagogical model in one school was either too limited or insufficient to warrant generalization on these aspects.

## Author contributions

Jun Karren V. Caparoso: conceptualization, data collection and analysis, writing the original draft, reviewing, and editing; Antriman V. Orleans: conceptualization and supervision. All authors have approved the final version of the manuscript for publication.

## Use of AI tools declaration

The authors have not used Artificial Intelligence (AI) tools in writing this article.

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## Conflict of interest

The authors declare no conflict of interest in this paper.

## Ethics declaration

This study was granted Clearance to Proceed (REC Code: 102418-285) and Certificate of Compliance (REC Code: 05252021-61) by the Research Ethics Committee of Philippine Normal University-Manila.

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