Serious Games Model for Higher-Order Thinking Skills in Science Education

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***Abstract*—The popularity of digital games has led to the emergence of serious games, which are developed with specific purposes beyond mere entertainment. Serious games in education represent more innovative and current pedagogical approaches. However, the existing digital games have been shown to improve critical thinking skills, although there is still a limited amount of research on science education. A preliminary study has found that digital games developed for science teaching do not incorporate all aspects of Higher-Order Thinking Skills (HOTS). This study aims to identify and validate game components and design a serious game model for HOTS in science education (PKBATDPS Model), which was validated using the Electric Circuit prototype. The study is divided into four phases: analysis, design, development and evaluation. During the analysis phase, the components of the PKBATDPS model were identified. The Electric Circuit prototype was evaluated using a quasi-experimental procedure that included pre-tests, post-tests, and learning motivation questionnaires. The experiment involved 32 elementary students; 16 in the experimental group used the serious games application prototype, whereas 16 in the control group received the traditional method. The results show that the PKBATDPS Model can be effectively used to increase students' HOTS and motivation in science education.**

Keywords—Serious game; Higher-Order Thinking (HOT) skills; science education; game element; learning element

I. Introduction

Serious games are interactive digital games designed with specific purposes other than entertainment that can train and educate players [1][2]. In recent years, serious games have been developed and used in multiple fields, including the military, advertising, education, simulation, and healthcare [3][4]. In the field of education, serious games are one of the technological tools used as a teaching aid to meet the needs of the current generation. This generation is born in the age of digital technology, commonly known as the Digital Native generation, and is already familiar with technology [5]. Today's generation prefers active learning that is interactive, enjoyable, and focused on problem solving. Therefore, the use of serious games as teaching aids is in line with educational objectives, as they are designed to provide an interactive and exciting learning experience.

According to [6], serious games are a form of student-centred approach that have the potential to build students' understanding of learning. Serious games have grown significantly and widely used in many different subjects to support the learning process and provide learning experiences such as in mathematics [7], science [8], history [9] and language [10]. The use of serious games in education has been shown to have the potential to foster an engaging and interactive learning environment that cultivates critical thinking skills among students. This is because serious games involve the development of the mind and require a deeper level of thinking [6].

Hence, the integration of serious games in education should be broadened to all academic disciplines, with particular emphasis on science. It is regarded as challenging due to its abstract nature and Higher Order Thinking Skills (HOTS) presence. HOTS refers to the highest level of cognitive processing in the cognitive function hierarchy. HOTS entails receiving, storing, delivering, and synthesising new information with existing knowledge to resolve intricate problems [11]. Regarded as pivotal competencies, HOTS contribute to shaping a generation equipped with innovative thinking and the requisite abilities to confront the demands of the 21st century [12].

In Malaysia, the incorporation of thinking skills into the curriculum began in the early years of 1993, focusing on promoting critical and creative thinking skills [13][14]. In 2011, the curriculum was further enhanced to include HOTS, to stimulate students' thinking skills [13]. However, issues related to ineffective science teaching methods have hindered the successful implementation of the HOTS [15]. Traditional teaching methods, which emphasise cognitive activities such as memorisation, recall, and comprehension, have been deemed inadequate to effectively implement HOTS [12]. One-way communication learning methods, such as "note-taking and lecturing," are also viewed as teacher-centred instructional approaches. This method restricts students' ability to think critically and generate and develop their ideas, particularly in science education.

Currently, research on the design of games for science education is also being conducted. According to [16][17], serious games emerge as an effective tool that offer engaging and enjoyable experiences for enhancing learning in science. This is because serious games offer students the opportunity to engage in other alternatives to learning in simulation or experiments [18][19]. Moreover, serious games provide a more active and interactive learning experience that can stimulate interest, increase motivation [2], increase engagement [16] and improve academic achievement in science [20].

However, one of the identified issues in serious game design is the weakness in terms of learning content. In the design of games for science education, alignment with local curriculum content is imperative to meet the requirements of the national education system and the students' needs. This necessity arises due to disparities in curriculum content, which render existing games on the market less suitable for instructional purposes within the Malaysian context [21].

Previous research has investigated digital games to enhance critical thinking skills [22], yet there remains a scarcity of studies specifically focusing on science education [23]. Preliminary investigations have revealed that digital games designed for science education often lack the integration of all components of HOTS. Additionally, the content of these digital games frequently fails to establish connections with real-life scenarios [21]. Therefore, the collaboration between game developers and subject matter experts is needed to ensure that the serious game design is in line with the learning content that emphasises the HOTS in science education. Hence, developing a model for HOTS games in science education is needed to captivate students' interest and enhance their HOTS capabilities within the subject matter.

II. Method

This study utilized the Design and Develop Research (DDR) approach, which encompasses four primary phases: analysis, design, development and evaluation. Data collection employed a mixed-methods approach, integrating both qualitative and quantitative research methodologies.

A. Analysis Phase

The analysis phase serves as the initial step in the study to ascertain the research requirements. During this phase, issues and problems, along with elements of the game model, were identified. The activities include a comprehensive literature review, a survey, and unstructured interviews. The literature explored students' perceptions of science education, the challenges of implementing HOTS in science education, and the design of serious games. The survey aimed to capture students' perceptions of the science subject. Unstructured interviews were conducted with a panel of eight experts, comprising six science teachers and two School Improvement Specialist Coaches Plus (SIC+) science officers, to identify HOTS implementation in science education and the role of digital games in educational settings. Fig. 1 summarizes the activities performed in this phase.

B. Design Phase

In this phase, four key activities were involved: component grouping, component mapping, low-fidelity prototype design, and initial component validation. All elements were systematically organized and mapped into different components of the PKBATDPS Model. The initial PKBATDPS Model was categorized into two primary components: learning components and game components. To illustrate the interrelationship between these components, the research model was depicted in diagram form, providing a comprehensive overview.

Subsequently, the components of the PKBATDPS Model in the low-fidelity prototype, namely the Electric Circuit storyboard, were implemented. The activities are developed based on the Standard Curriculum and Assessment Document for Year 5 Science, specifically the electric topic outlined in the Primary School Standard Curriculum. This approach ensures that the prototype is grounded in the existing educational framework and aligns with the instructional resources available to students.

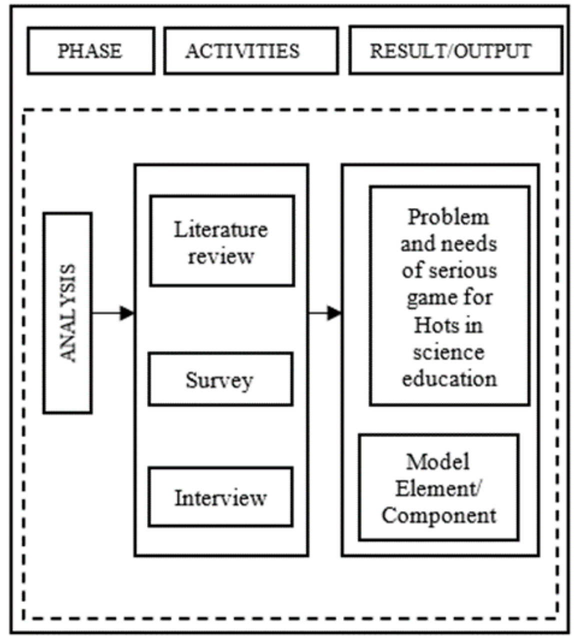

Fig. 1. The activities in the analysis phase.

The initial validation of the PKBATDPS Model components was conducted through heuristic evaluation by assessing the low-fidelity prototype. The validation of the PKBATDPS Model elements engaged two SISC+ officers from the District Education Office (DEO) and three university lecturers. The number of expert evaluators selected for this evaluation is aligned with the recommendations of [24], which advocate for a panel size of three to five individuals. The evaluators were chosen based on their expertise and experience in science education, as well as their proficiency in software and game assessment. Expert validation was conducted to ascertain the implementation of each model element in the game interface design.

The questionnaire consists of three sections: Demographic Information, Learning, and Game. Each expert evaluator responds to questions using a five-point Likert scale, where 1 indicates "Strongly Disagree", 2 “Disagree”, 3 “Neutral”, 4 “Agree” and 5 indicates "Strongly Agree". The assessment results are analysed using the Interquartile Range (IQR) to determine consensus in evaluating expert opinions [25][26]. The IQR is a measure of variability based on the distribution of data divided into three parts: the first quartile (Q1), the median or second quartile (Q2) and the third quartile (Q3). The IQR value is calculated by subtracting Q1 from Q3. Elements with an IQR value of 1 or less (≤ 1) are retained, while those with IQR value greater than (>1) are eliminated. Fig. 2 provides a summary of the activities performed in this phase.

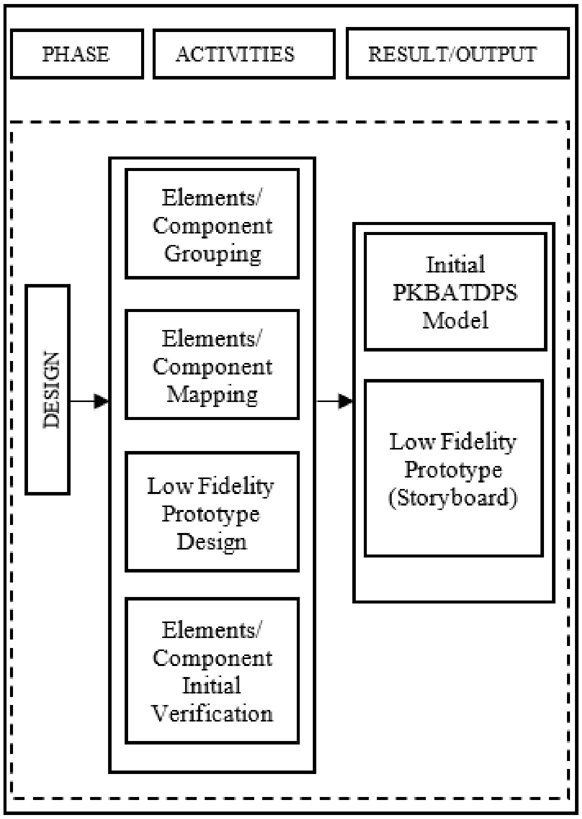

Fig. 2. The activities in the design phase.

C. Development Phase

The development phase involves the implementation of the components of the PKBATDPS Model, which have been refined based on feedback from experts, into the high-fidelity prototype, namely the Electric Circuit game prototype. The development of the Electric Circuit game prototype utilized three software applications: Adobe Photoshop, Autodesk 3D Max, and UNITY, which were employed in the process of creating the game interface. Subsequently, the development of modules, quizzes, and games was executed based on the content design established during the design phase.

The Electric Circuit game prototype is software played offline and is based on self-directed learning, allowing students to learn according to their convenience in terms of place and time.

The game prototype encompasses various subtopics, including electric power sources, complete electric circuits, and safety measures for handling electrical equipment, all presented within a narrative framework. The developmental process of the prototype unfolds progressively through different levels of the game. Advancement from one level to the next entails activities designed to cultivate HOTS, such as application, analysis, evaluation, and creation. This pedagogical approach mirrors Bloom's taxonomy (1985), which underscores the necessity for learners to master each instructional unit before progressing to subsequent ones.

Finally, a meeting was convened with the science subject teachers to provide a concise overview of the study's objectives, evaluation methods, and the prototype employed. During this session, teachers received training on the operational aspects of the Electric Circuit game prototype prior to the actual implementation and evaluation. This preparatory measure ensured that teachers were well-equipped to facilitate the learning experience and offer constructive feedback during the assessment phase, thereby enhancing the overall efficacy of the evaluation process. Fig. 3 shows the activities conducted during this phase.

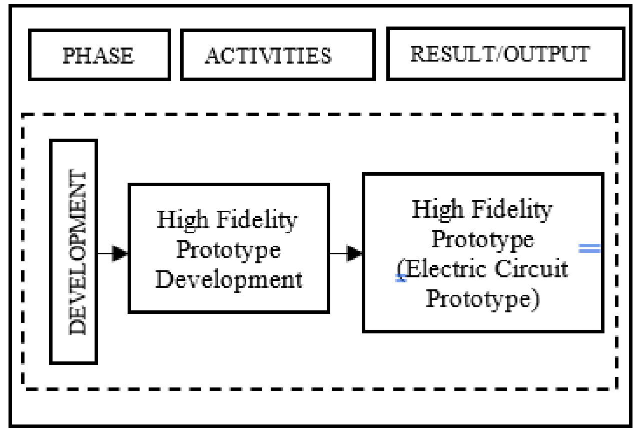

Fig. 3. The activities in the development phase.

D. Evaluation Phase

The implementation and evaluation phases involve three activities: Instrument Development, Content validation and Pilot Study, and Evaluation of the Electric Circuit game prototype. The evaluation process involves 32 fifth-grade students, divided into control and experimental groups. Participants are selected based on equivalent achievement scores from previous science assessments. This aligns with the recommendations suggesting a suitable sample size of 10 to 20 participants for comparative experimental studies [27][25]. Additionally, a minimum sample size of 15 participants is recommended for quantitative experimental research [28][29].

The independent variable in this study is the teaching method, specifically the use of serious games compared to traditional instructional methods. The dependent variables are students' scores on the science HOTS test and their motivation survey scores in science. The evaluation instrument is divided into two types: pre- and post-tests (and a motivation survey). The pre-test comprises a series of questions on the electric topic in science, generated based on the Primary School Standard Curriculum syllabus, textbooks, and reference materials for fifth-grade science. This test aims to assess students' HOTS levels in science before and after exposure to serious games.

The test instruments consist of two sections: Demographic Information and science questions which are categorised into four types. The test instruments were developed with the assistance of several teachers and subsequently reviewed by two subject-matter experts skilled in the relevant field. This expert review is essential to ensure the accuracy of the constructs and the clarity of the research instrument content, as recommended by [30].

The motivation questionnaire was then developed based on Keller's (1987) ARCS model, which includes the elements of Attention, Relevance, Confidence, and Satisfaction. This instrument was created to assess students' motivation levels before and after science learning using serious games. The questionnaire comprises two sections: Section A gathers demographic information, while Section B includes four constructs and 27 items measured using a 5-point Likert scale to evaluate student motivation in science.

A pilot study involving 15 randomly selected fifth-grade students was conducted to evaluate the reliability of a motivation questionnaire within the context of science education. The data collected were analyzed using Cronbach's alpha, following Cronbach's (1946) methodology, with IBM SPSS Statistics version 16.0. The overall reliability score of the instrument was 0.81, indicating a high level of reliability. This result suggests that the motivation questionnaire is suitable for use in actual research [31][32]. Fig. 4 illustrates the activities during the implementation and evaluation phases.

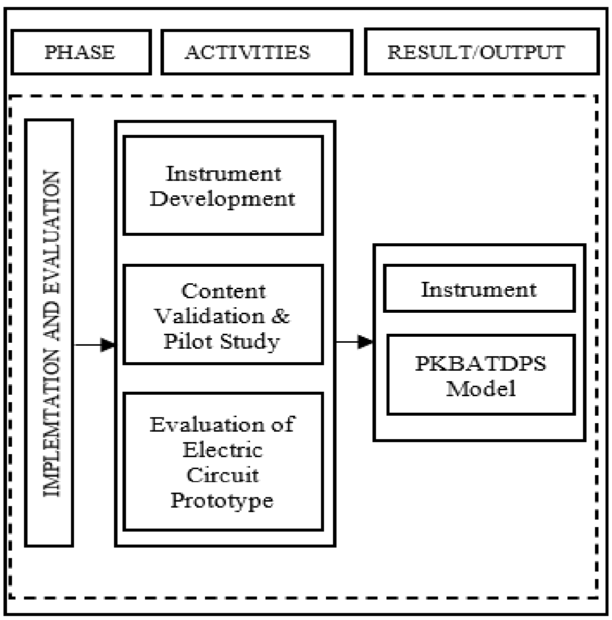

Fig. 4. The activities in the evaluation phase.

III. Results and Discussion

This study successfully identified 10 game elements categorised into two main components in the PKBATDPS Model. These ten elements consist of four learning elements and six game elements. The learning elements consist of learning objectives, constructivism learning theory, science subject content emphasising HOTS, and the ARCS motivation model. Meanwhile, the game elements consist of objectives, fantasy, challenge, feedback, control, and rule. One for both learning and game components. This indicates that the experts agreed that all assessed components of the PKBATDPS Model, as depicted in Fig. 5, were effectively implemented in this low-fidelity prototype.

Therefore, no elements needed to be eliminated or added. However, the experts provided feedback and suggestions for improving the design of the Electric Circuit prototype, particularly concerning the implementation of goal elements. They recommended that the game goal element be more clearly indicated at the end of the game to show that the game has successfully achieved the stated goal presented at the beginning. Improvements were incorporated during the development of the Electric Circuit prototype. Table I presents the learning and game elements validated by the experts, along with their IQR values.

TABLE I. PKBATDPS Model Elements Validated by Experts (IQR Value)

Bil	**Learning Element**	**P1**	**P2**	**P3**	**P4**	**P5**	**Q1**	**Q3**	**IQR**
1.	Learning Goal	5	5	4	5	4	4	5	1
2.	Constructivism Learning Theory	4	4	5	5	4	4	5	1
3.	Science Learning Content (Based on HOTS Element)	4	4	5	4	5	4	5	1
4.	ARCS Model Motivation	4	5	4	5	4	4	5	1
	Game Element	**P1**	**P2**	**P3**	**P4**	**P5**	**Q1**	**Q3**	**IQR**
1.	Goal	5	5	4	4	5	4	5	1
2.	Fantasy	5	4	5	4	4	4	5	1
3.	Challenge	5	5	4	4	4	4	5	1
4.	Feedback	5	5	4	4	5	4	5	1
5.	Control	5	5	4	4	5	4	5	1
6.	Rule	5	4	5	5	4	4	5	1

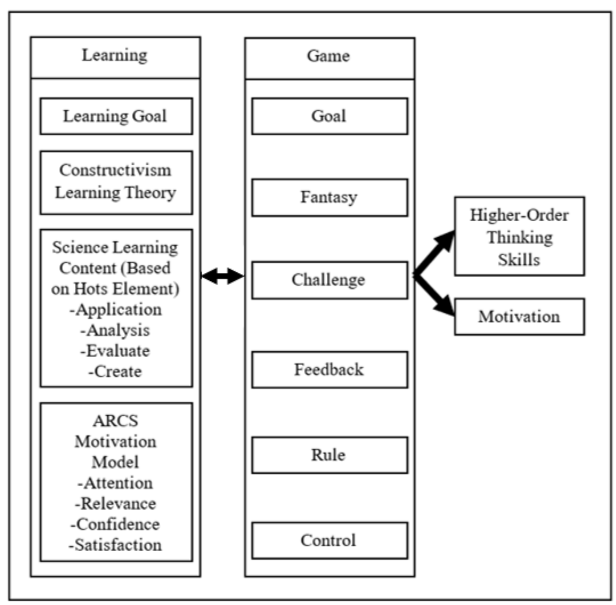

Fig. 5. PKBATDPS model.

The evaluation of the Electric Circuit prototype was conducted using a quasi-experimental method, which included pre-tests, post-tests, and learning motivation questionnaires. Two groups were involved: a control group and an experimental group.

E. Analysis of HOTS

The result revealed a significant difference in the mean scores of pre-tests and post-tests for the experimental group. Table II shows the mean score for pre-test of 16.38 and post-test of 64.63. These results indicate that there is an improvement in HOTS among students after using serious game applications in science education.

TABLE II. T-TEST RESULT OF THE PRE AND POST-TESTS FOR EXPERIMENTAL GROUP

Experiment Group	N	Mean	Standard Deviations	t	p
Pre-Test	16	16.38	9.13	16.15	0.000
Post-Test	16	64.63	9.95		

Next, the result indicated a significant difference in the mean post-test scores between the experimental and control groups. Table III shows the mean post-test score for the experimental group was 64.63, higher than the control group's mean post-test score of 29.38. These results indicated that the experiment group who engaged with the serious game application demonstrated better HOTS than the control group who received the traditional method in science.

TABLE III. T-TEST RESULT OF THE POST-TEST SCORE FOR THE EXPERIMENTAL AND THE CONTROL GROUP

Sample	Mean	Standard Deviations	t	p
Experiment Group	64.63	9.95	11.01	.000
Control Group	29.38	8.05		

F. Analysis of Motivation

The result demonstrated a significant difference in the mean scores of motivation before and after using serious game applications in science education. Table IV shows that the mean motivation score after using serious game applications was 4.45, higher than before using serious game applications. These results indicated that the students' motivation increased after using serious game applications in science education.

TABLE IV. TEST RESULT OF THE LEARNING MOTIVATION POST-QUESTIONNAIRE RATING FOR EXPERIMENTAL GROUP

Experiment Group	N	Mean	Standard Deviations	t	p
Motivation-Before	16	4.00	.30	5.39	0.000
Motivation-After	16	4.45	.28		

Then, the motivation result between the two groups indicated a significant difference in the mean motivation score. Table V shows that the mean motivation score for the experiment group was 4.45 higher compared to the control group mean score of 4.00. These results indicate that students who used the serious game application prototype in science education demonstrated higher motivation compared to those who learnt through traditional methods.

TABLE V. T-TEST RESULT OF THE LEARNING MOTIVATION POST-QUESTIONNAIRE RATING FOR EXPERIMENTAL GROUP AND CONTROL GROUP

Sample	Mean	Standard Deviations	t	p
Experiment Group	4.45	.28	3.98	.000
Control Group	3.95	.41		

Overall, these assessment results demonstrate that using the Electric Circuit prototype effectively enhances Higher-Order Thinking Skills (HOTS) and student motivation in science education. Consequently, it can be concluded that the PKBATDPS Model, as implemented in the Electric Circuit prototype, can be utilized to cultivate students' HOTS in science education. Additionally, it has the potential to increase students' motivation and interest in science education.

IV. CONCLUSION

This study successfully identified 10 elements categorised into two main components in the PKBATDPS Model and implemented in Electric Circuit prototype. The evaluation of the Electric Circuit prototype was conducted using a quasi-experimental method, which included pre-tests, post-tests, and learning motivation questionnaires. Two groups were involved: a control group and an experimental group. The experimental group participated in learning activities using the serious game application while the control group engaged in traditional learning method. The results show that students in the experiment group demonstrated a significant improvement in HOTS after using serious game applications in science education. In addition, the results reveal that the student in the experiment group who engaged with the serious game application demonstrated better HOTS than the student in the control group who received the traditional method in science. Observations showed that the students in the experimental group enjoy playing games with science. In terms of learning motivation, the result shows that the students' motivation in experiment group increased after using serious game application in science education. Furthermore, the result indicate that students who used the serious game application prototype in science education demonstrated higher motivation compared to those who learned through traditional methods. These results indicate that the implementation of serious game application in learning provides more engaging and interactive learning environment that cultivate HOTS and increase motivation in science education. Therefore, serious games can be considered a novel learning method that is more engaging, interactive, and effective in enhancing HOTS and student motivation in science education. The evaluation results of the Electric Circuit game prototype validate the proposed PKBATDPS Model suggested by this study. The results demonstrate that the objectives of the study have been achieved. However, further research can be carried out by adding learning elements and other game elements to challenge the player's level of thinking at a high level.

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