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Effects of Multi-Genre Digital Game-Based Instruction on Students' Conceptual Understanding, Argumentation Skills, and Learning Experiences

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ABSTRACT Studies have shown that although traditional instruction is effective in developing students' conceptual understanding, it lacks in strengthening their thinking skills. To enhance traditional instruction and establish an approach using game-based instruction, this study developed Multi-genre digital Game-based Instruction (MGI), which integrates various game genres—situated and competitive—with traditional instruction. A total of 115 fourth-graders (9–10 years old) of 4 classes participated in the study, of which 2 classes made up the MGI (experimental) group and the other 2, the traditional instruction (control) group. Quantitative and qualitative data were collected to answer research questions by examining the comparative effectiveness of the two groups separately as well as the effectiveness by achievement level, and exploring students' learning experiences. Findings showed that using MGI resulted in a significant improvement in conceptual understanding and argumentation skills compared to those who were taught only with traditional instruction. Furthermore, it showed that MGI was significantly more effective than traditional instruction in improving low-achieving students' conceptual understanding, as well as improving argumentation skills for all achievement levels. Students' learning experiences with MGI showed how the proposed instruction is superior compared to existing traditional instruction.

INDEX TERMS Achievement levels, game-based learning, instruction model, learning effectiveness, scientific argumentation.

I. INTRODUCTION

To thrive in the knowledge-based economy of the 21st century, a solid foundation of scientific literacy is essential for society's innovation and sustainability. The Programme for International Student Assessment evaluated students' scientific literacy based not only on the extent of students' knowledge but also on how well their reasoning is [1]. Thus, students' ability to reason, analyze data, and construct and use evidence-based arguments is defined as the key content of scientific literacy. With this, there is an urgent need for educators to develop curricula and instruction to enhance scientific literacy.

Because of this demand, increasing attention has been directed to the potential and effects of using computer technologies on improving student science learning [2]–[5]. In recent years, digital game-based instruction began to be incorporated into classrooms. Such has been seen to demonstrate a positive impact on learning [6] with its high interactivity. Digital game-based instruction also provides a motivating and engaging learning environment for students in ways that traditional instruction cannot [7], [8].

The adoption of this instruction was slower than expected, however, because of the lack of adequate instructional materials and teachers' limited capability of integrating games into their instruction [9]. Thus, this study aims to develop game-based instructional courseware to improve students' science learning, and support how teachers integrate games into their instruction.

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There is insufficient research in terms of which game genre is most likely to build students' scientific literacy, and whether a single-genre digital game, such as role-playing, adventure, strategy, drills-and-practice [10], could well serve the learning needs in a complex science teaching environment, which frequently includes conceptualization, hands-on experiments, problem-solving, scientific reasoning, etc. Thus, this study goes beyond the common use of a single-genre digital game by creating multiple-game genre courseware to improve students' science learning and support teachers' integration of games into their instruction. The theoretical frameworks, including situated learning theory and motivation theory, guide the design of an instructional model labeled Multi-genre digital Game-based Instruction (MGI).

To evaluate MGI's practicability, the topic of light, designed for fourth graders, was selected, and its instructional design and learning courseware were developed. The comparative effectiveness of MGI on students' science learning, specifically, their conceptual understanding and argumentation skills, was examined. Because many studies show that digital game-based instruction may have varying effects depending on the students' level [7], [11], [12], this study looked into the details on how MGI affects students with different achievement levels (high, medium, or low).

This study aims to answer the following research questions (RQs):

- **RQ1.** What is the comparative effectiveness between MGI and traditional instruction on building students' conceptual understanding and argumentation skills?
- **RQ2.** What is the comparative effectiveness between MGI and traditional instruction on science learning among students of different achievement levels?
- **RQ3.** What learning experiences did students perceive in MGI?

II. THEORETICAL BACKGROUND

A. CONCEPTUAL UNDERSTANDING AND ARGUMENTATIONS SKILLS IN SCIENCE LEARNING

Scientific literacy is essential for students' preparation for higher education and employment. To be scientifically literate, one needs to be able to acquire conceptual understanding and comprehend how science is connected and applied. The vision represented in one major science education reformation effort entitled "Next Generation Science Standards (NGSS)" involves student engagement at the nexus of the following three dimensions: (1) science and engineering practices; (2) crosscutting concepts; and (3) disciplinary core ideas [13]. Instead of treating these three science dimensions as separate and distinct entities, the NGSS focus on a more in-depth understanding of core ideas and concepts as well as the application of conceptual understanding in scientific inquiries and engineering practices. Furthermore, the link between scientific and engineering practices with scientific concepts / core ideas is established through the process of argumentation, which plays an essential role in building students' scientific literacy, as it is important in the process of thinking and scientific reasoning, and the development of conceptual understanding [14], [15].

The inclusion of argumentation has been emphasized in school science learning [5], [16]–[18]. Toulmin's argumentation model [18] provides a framework for constructing arguments to help learners think critically and logically. Simon [20] highlighted the advantages of using Toulmin's argument pattern (TAP) in teachers' active promotion of argumentative classroom discourses among the students. TAP has five essential components: (1) claim—the conclusion, proposition, or assertion; (2) data—the evidence that supports the claim; (3) warrant—an explanation of the relation between the claim and the data; (4) backing—basic assumption to support the warrant; and (5) rebuttal—the conditions to discard the claim [19], [21]. In summary, students need to incorporate scientific knowledge to make a claim, use data and evidence to support the claim, and reason with justification, as well as provide rebuttals to refute opposing ideas.

However, research has shown that students struggle with scientific argumentation and display a range of errors in argumentation [22]. Improving students' argumentation skills in science classrooms is not an easy task [18]. Difficulties have been highlighted in a study by Driver *et al.* [23], in which they suggested that the complexities of scientific argumentation, the lack of opportunities for the practice, and the lack of teachers' pedagogical skills were impediments to students' learning of argumentation skills. Various approaches have been applied to help students gain a conceptual understanding of scientific knowledge and develop the ability to engage in argumentation. For this, recent studies suggest that the incorporation of technology into traditional instruction has the potential to enhance science learning and support argumentation [24].

B. GAME-BASED INSTRUCTION

There has been a growing interest among researchers in the potential of the enhancement of science education through technology-enhanced instruction such as game-based instruction [25]. A study by Lu and Lien [26] revealed that students have a twofold perception of their game-based learning: learning and playing. This perception of playing contributes to students' self-efficacy in science learning. A meta-analysis by Wouters *et al.* [27] found that digital game-based instruction is more effective than traditional instruction in terms of content learning and retention. Another analysis showed that digital game-based instruction supports a productive learning environment and enhances students' learning outcomes in three broad domains: cognitive, intrapersonal, and interpersonal [2]. The study by Hussein *et al.* [6] on game-based learning in elementary science education showed the potential of digital game-based learning in fostering students' knowledge development, eventually suggesting that studies should extend to other learning domains as well. On the other hand, findings wherein learning with game-based instruction does not always lead to expected increases in all aspects of engagement and learning outcomes have also been reported [28]. Considering the unevenness of evidence for games as learning tools, the current study seeks to gain a better understanding of the effect of digital game-based instruction on the aspect of conceptual understanding and argumentation skill in science learning.

The authors' research team has engaged in research about game-based instruction in science education. In a study of teaching simple machines to sixth-grade students using game-based instruction in an after-class activity, results indicated that students were actively engaged in learning throughout the process and showed improvement in conceptual understanding and skills of scientific inquiry [29]. In a study by Chen *et al.* [30], who developed an educational game teaching everyday science, results showed that digital game-based instruction had a positive impact on students' conceptual understanding and the shaping of their cultural identities and beliefs. Studies by Hussein *et al.* [31] and Chen *et al.* [7] examined the effectiveness of digital game-based learning on elementary students' learning of critical thinking skills and argumentation skills, respectively, and showed how the educational game significantly improved students' thinking skills in science.

Notably, many studies have also revealed that digital game-based instruction has varying degrees of effectiveness on students with different achievement levels. Ku *et al.* [11] investigated the effectiveness of digital game-based instruction on high- and low-achieving students. Their study revealed that digital game-based instruction enhanced students' learning better than traditional instruction, and further indicated the former as a more effective approach for low-achieving students when comparing their performance under traditional instruction only. Moreover, Sadler, Romine, Stuart, and Merle-Johnson [11] revealed that digital game-based learning is more effective for average students than high-achieving students. This was further supported by Israel *et al.* [32], as their study showed that students' learning preparatory status (pretest scores, reading proficiency, etc.) could influence their learning growth in digital game-based instruction. The study by Chen *et al.* [7], on the other hand, reported that the comparative effectiveness of instructional approaches (i.e., game-based vs. traditional learning) is affected differently by students' achieving levels, but this phenomenon needs further verification.

C. SINGLE- TO MULTI-GENRE DIGITAL GAMES

Genre frameworks, including action, adventure, fighting, logic, simulation, sports, and strategy, have been used to classify games [33], [34]. In an analysis by Hainey *et al.* [10] on the application of digital game-based instruction on the primary education level, they categorized games used in instruction by their genre framework. Here, they found that many game genres were in use, which included: action, adventure, generic, puzzle, role-playing, simulation, strategy, virtual reality, and virtual world; however, other genres, such as fighting, platform, and racing, were not found in the instruction. Boyle *et al.* [35] identified that adventure and role-playing are the genres most commonly used in instruction.

Despite these studies, however, there is still no common reference in terms of game categorization by genres. Depending on its gameplay interaction, one educational game can be classified in more ways than one and, therefore, can be classified under two or more genres; furthermore, many analyses on the effectiveness of specific types of digital game-based instruction claim to identify a game as belonging to only one genre despite it including other elements that would make it qualified as another. As recommended by the framework of the National Research Council [36, p. 253] in the United States, instructions need to incorporate a range of approaches to using their full potential for enriching students' learning flexibly; thus, using 1 game genre for a short instructional activity (e.g., 10 min or 1 class session) may be ideal but may not be practical in an actual classroom setting, which usually takes more than 10 class sessions for teaching a scientific core topic. Game-based instruction would, in nature, call for a multi-genre approach to meet the needs of teaching and learning. A study by Kim *et al.* [37] echoed the trend and used a blended-genre digital game of storyline and challenges in a fourth-grade classroom. Their study found that this approach could have contributed to the positive effects on students' motivation. Noteworthily, this study did not explore how students' learning of knowledge and thinking skills were affected.

D. SITUATED LEARNING THEORY AND MOTIVATION THEORY

1) SITUATED LEARNING THEORY

The situated learning theory has influenced many aspects of education and is one of the vital foundations of many game genres. The situated learning theory of Lave and Wenger [38] views learning as a process of participation in a community of practice wherein learners acquire, develop, and use cognitive tools in authentic activities. Derived from Vygotsky's cultural–historical framework, meaning and subsequent learning are produced through a process of the collaborative and social nature of meaning making [39]. Furthermore, Sadler [40] highlighted the value of applying situated learning frameworks in his analysis of situated learning in science education.

Technology is capable of expanding the power and flexibility of resources that can be used to support various components of learning [41], [42]. Acknowledging the importance of situated learning in the context of promoting more in-depth understanding, the contents of this study's instruction unit (light) are linked with a storyline of real-world scenarios to make learning connect to real-world events and students' personal experiences. Students choose an avatar to explore through various situations that would require conceptual learning and the use of argumentation skills. The multisensory settings and interactive elements offer a learning environment in which students can become absorbed and engaged in embedded science learning activities. They would face challenges in the game and complete tasks that simulate real-world context.

2) MOTIVATION THEORY

Many educators believe in the potential of digital game-based instruction in enhancing students' motivation as well as their interest in and commitment to learning [43]. Keller [44] called for motivational design as an integration of theory, research, design, and practice. Motivation influences students' learning behaviors as well as impact their academic achievement. Social scientists have been studying motivation to understand what motivates our behavior, how this happens, and why it does. Maslow [45] stated that people are motivated to achieve specific needs. When one need is fulfilled, a person seeks to fulfill the next one and so on. Bandura [46] defined the term "self-efficacy beliefs" as the self-perceptions that individuals hold about their capacities and discussed how such self-efficacy beliefs provide the foundation for human motivation, well-being, and personal accomplishment.

In addition, competition is considered as an effective technique in motivating people to learn and excel. Competition is regarded as a goal-oriented condition that has an impact on both the direction and intensity of a person's motivation [47], [48]. Atanasijevic-Kunc *et al.* [49] suggest that competition in digital game-based instruction stimulates student interest and increases the efficiency of the learning process. Cagiltay *et al.* [50] found that motivation and posttest scores of learners improve significantly when a competitive environment is created through digital game-based instruction. Incorporating the motivating theory, the MGI courseware adds an element of competition and, through this, intends to increase motivation by drawing students' attention and excitement. Receiving competition rewards, students would gain a sense of achievement and satisfaction throughout the learning unit, thereby building a positive self-efficacy belief.

In summary, the study embraces a sound theoretical framework, including situated learning theory and motivation theory. MGI simulates real-world context and makes learning connect to students' personal experiences within a motivating and engaging learning environment.

III. RESEARCH METHODS

A. RESEARCH DESIGN

Both quantitative and qualitative approaches were used in this study (Table 1). The research used a two-group quasi-experimental design wherein the control group was taught by traditional instruction, while the experimental group was taught by MGI. Two tests—Scientific Concept Test (SCT) and Scientific Argumentation Skills Test (SAST)—were used to monitor students' learning, before and after experimental treatments. A semistructured interview was conducted after the experimental instruction to collect students' opinions regarding their learning experiences during MGI. All classes were made part of the students' course of study and treated as ordinary classroom sessions.

TABLE 1. Research design of this study.

Group	Pretest	Treatment	Posttest	Interview
Traditional instruction ($n = 57$)	O_1[a] O_2[b]	Traditional instruction	O_1 O_2	
MGI ($n = 58$)	O_1 O_2	MGI[c]	O_1 O_2	O_3[d]

[a]O_1: Scientific Concept test (SCT)
[b]O_2: Scientific Argumentation Skills Test (SAST)
[c]MGI: Multi-genre digital Game-based Instruction
[d]O_3: Semistructured interview ($n = 12$)

B. PARTICIPANTS

The participants of the study were made up of 115 fourth-grade students, aged 9–10, of 4 classes from an elementary school in Taipei, Taiwan. These students belong to the S-type normal class grouping, in which students with various learning achievement levels are equally distributed into each class. Among the 4 classes, 2 classes were selected as the MGI (experimental) group, with a total of 29 boys and 29 girls. The other 2 classes were assigned to the traditional instruction (control) group, with a total of 28 boys and 29 girls. The four classes were taught by the same teacher with seven years of experience in science teaching. The experiment obtained consent from the school and was made part of the lesson plan reported in the parent-teacher symposium routinely held at the beginning of a semester, with the consent of the students' parents.

In comparison to the effect of MGI on students with different achievement levels, students were divided into high-, medium-, and low-achieving groups in terms of their academic achievement in science for the previous semester. The top 27% was considered as the high-achieving group, the bottom 27% as the low-achieving group, and the remaining students as the medium-achieving group [51].

After the experimental instruction, 12 students from the MGI group, made up of 4 students from each level of achievement, were randomly selected and interviewed to collect opinions concerning their learning experiences with MGI. The identification numbers of the 12 students were as follows: S0915M-1, S0918F-1, S0902M-2, S0919F-2, S0916F-3, S0903M-3, S1028F-1, S1025F-1, S1010M-2, S1021F-2, S1017F-3, and S1012M-3. (Code: S1234 stands for students' number; M/F for their gender; -1, -2 and-3 for low-, medium-, and high-achieving group, respectively.)

C. INSTRUCTIONAL INSTRUMENTS: "MAGIC OF LIGHT" UNIT

The goals of science education established by the National Curriculum Guidelines [52] are to enhance students' interest in learning and improve their reasoning as well as their logical and thinking skills. The instruction instrument, the ''Magic of Light'' unit, follows a textbook-based sequence and includes three sub-units: (1) light travels in straight lines; (2) reflection of light; and (3) refraction of light. In addition, the last class session connects concepts of light with real-world examples and real-life experiences. In this study, both the MGI and traditional instruction groups received instruction that spanned 18 class sessions (40 min for each class, 3 times a week, and lasted 6 weeks; Table 2).

TABLE 2. Comparison of instructional methods of traditional instruction and multi-genre digital game-based instruction groups.

Dimensions	Traditional Instruction (Control Group)	MGI[a] (Experimental Group)
Course contents	"Magic of Light" unit in the textbook for fourth graders	
Length	18 sessions in 6 weeks with 720 min in total	
Resources	Textbook PowerPoint presentation[b]	Textbook MGI games: Situated learning game (UeBond) Competitive game (Dodoya)
Equipment	Experiment equipment Projector	Experiment equipment Computers (1 unit for 2 students)
Venues	Classroom	Computer lab Classroom

[a]MGI: Multi-genre digital game-based instruction
[b]Supplied by the teacher.

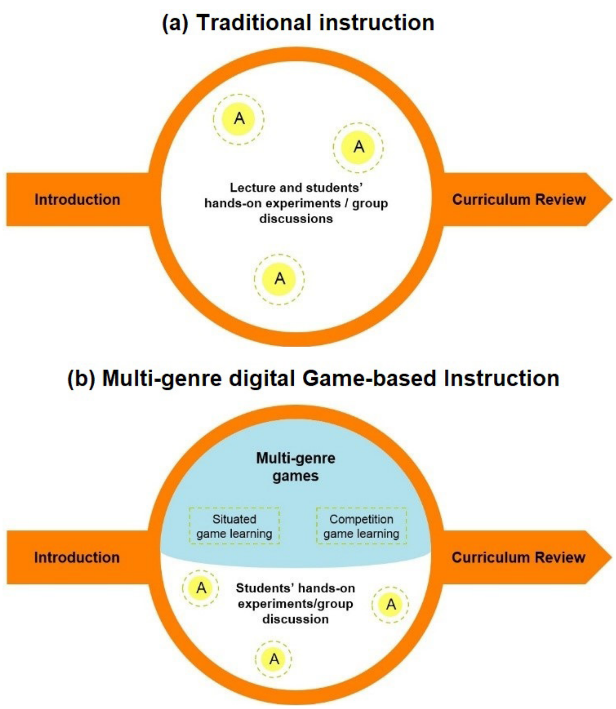

FIGURE 1. (a) The traditional instructional model vs. (b) Multi-genre digital Game-based Instruction (MGI) model. "A" stands for student' hands-on experiment or group discussion.

In the control group, each of the above sub-unit was carried out in three phases (Fig. 1(a)). First, the introduction is the stage wherein the teacher begins with a brief unit introduction, connecting it with what has been taught previously. Second, the instruction is when the teacher teaches the unit by using lectures, conducting hands-on experiments, and facilitating discussions. Third and lastly, the review is when the teacher concludes with a unit review.

Similarly, the MGI model also proceeds with three phases (Fig. 1(b)). Its distinct difference from the traditional instructional model, however, is in the second phase. Instead of lecturing the content information, the teacher guides student learning in a digital game-learning environment; however, all hands-on experiments and group discussions were still kept as in the control group. The MGI courseware includes the UeBond (U(you) and Education BONDing) situated game with the genres of adventure and role-playing and the Dodoya competitive game with a drill-and-practice genre.

A research team led by the fourth author has developed dozens of educational games on different topics of science instruction in the past. The team created the game engines UeBond and Dodoya that allow school teachers who might not have the necessary programming experience to design educational games for their instructional purposes. The first author, a school teacher, worked with the fourth author's research team to develop the UeBond and Dodoya games on the topic of light. The development process is as follows.

The UeBond situated game includes genres of adventure and role-playing to build multisensory settings and interactive elements of a situated learning environment in which students engage in science learning. Students (as avatars) are asked to identify or recall natural phenomena they noticed in their everyday experience. In many cases, natural phenomena, video clips of scientific experiments, and science-related activities are used to connect to real-world experiences. Multiple forms of media, including texts, photos, diagrams, tables, audio clips, and videos, are used to present and explain science content (Fig. 2).

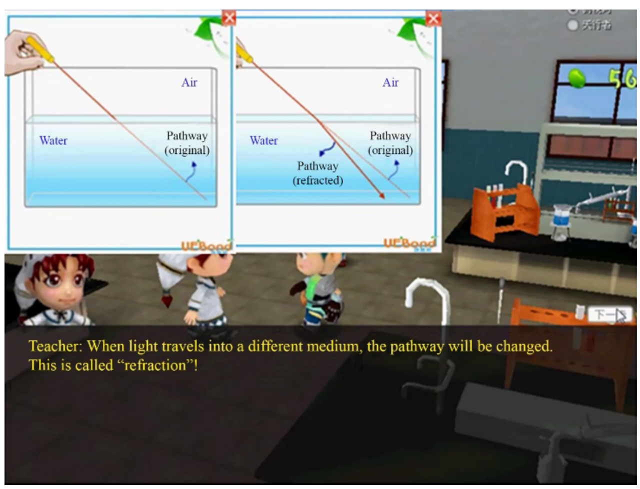

FIGURE 2. Scientific illustration and explanations to guide student' learning in the situated game. Texts have been translated from Chinese to English.

In addition, students are guided to practice their argumentation skills. The components of arguments, such as claim, data and evidence, backing, and warrant, are introduced with examples. Through the game, students can practice identifying evidence and claims in scenarios that show real-world examples (Fig. 3).

FIGURE 3. Learning argumentation skills in a situated learning environment. Texts have been translated from Chinese to English.

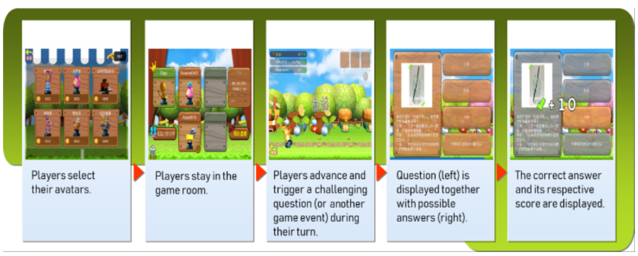

FIGURE 4. Interface and gameplay of the competitive game.

The Dodoya competitive game (Fig. 4) was designed to allow students to compete with each other in small groups (two to four) by testing their knowledge on what they have learned. The competition required each member of the groups to answer all questions, and the correct answers will be showed afterward. Each correct answer translates to a point for each member, becoming the basis of the results of the competition.

The Dodoya game contained 140 review questions concerning conceptual understanding and argumentation skills taught in the lessons. Among them, there are 40 questions regarding "light travels in straight lines," 43 questions regarding "refraction of light," and 57 questions regarding "reflection of light," (Fig. 5).

Throughout MGI, students receive feedback that guides them to the next step of learning. Hence, students may build confidence from timely feedback and be able to challenge themselves to solve the problems and complete the learning activities.

FIGURE 5. A sample item of the competitive game. Texts have been translated from Chinese to English.

Students spent about 85% of the time for the situated game (UeBond), and 15% for the competitive game (Dodoya). In the last part of MGI, the teacher concludes with a unit review, similar to that in the control group.

D. DATA COLLECTION AND DATA ANALYSIS

Scientific Concept Test (SCT) and Scientific Argumentation Skills Test (SAST) were developed by the first author and one experienced science teacher [7]. There are 13 questions in SCT, which aims to assess students' understanding of light in 3 areas: 1) light travels in straight lines; 2) reflection of light; and 3) refraction of light (Appendix A: Sample SCT Items).

SAST, a test of 25 questions, was developed based on Taiwan's Curriculum Guidelines listed under the section of "thinking skills" with the framework of Toulmin's argument components: claim, data, warrant, backing, and rebuttal. The purpose of SAST was to evaluate students' argumentation skills; therefore, the SAST questions included light-related concepts and other concepts students have learned previously (Appendix B: Sample SAST Items).

A total of 252 fifth-grade students who have learned the unit of light in fourth grade through traditional instruction were recruited to examine the reliability of both SCT and SAST. The results yielded a coefficient of KR20 of.72 and.81 for SCT and SAST, respectively, which appear to meet the accepted standards for internal consistency [53 p. 245] and the needs of this study. Statistical methods, including paired t-test, analysis of covariance (ANCOVA), and the Johnson-Neyman method were used to detect differences between groups. To study students' learning experience with MGI, 12 students were interviewed using the seven-item "Interview Questions for Exploring Students' Learning Experience in Using MGI" (Table 3).

Each question proceeded with two stages during the interview: first was about students' perceptions following a designated multilevel scale to get their self-determined responses, and second was about their reasons behind their perception. Take the second question as an example, which was about how the situated game affects the student's

TABLE 3. Interview questions for exploring students' learning experience in using multi-genre digital game-based instruction.

Section	Questions
(1) Effect of situated games on students' conceptual understanding and argumentation skills	(Q2): How does the UeBond game (situated game with adventure and role-playing genres) help you learn the concept of light? (Q3): How does the UeBond game help you learn scientific argumentation?
(2) Effect of competitive games on students' learning	(Q4): How do you like the Dodoya game (competitive game)? (Q5): How does the competitive game help your learning?
(3) Overall reflection	(Q1): Based on your overall learning experience, do you think you were learning or playing in your previous science classes? (Q6): Which part(s) of the program has/have helped your learning? (Q7): Which instructional approach (MGI or traditional instruction) would help you learn best, and why?

conceptual learning. The interviewer first asks the student, "Do you agree or disagree that UeBond helps your learning on the knowledge of 'light'?" Students were instructed to answer with the following designated levels: "Agree," "Somewhat Agree," or "Disagree." This interview method of soliciting students' self-determined perception on the designated scale reduced the ambiguity that might have emerged from researchers' subjective interpretation, thus ensuring that this study codes and reports students' views, opinions, or impressions in the most accurate way possible. During the second stage of the interview, the interviewer invited open-ended responses from students regarding their viewpoints, opinions, and impressions. When there is a discrepancy, follow-up questions would be asked for clarification. Students' responses to these questions were coded and analyzed to form the conclusion.

IV. RESULTS AND DISCUSSION

A. COMPARATIVE EFFECTIVENESS BETWEEN MGI AND TRADITIONAL INSTRUCTION ON CONCEPTUAL UNDERSTANDING AND ARGUMENTATION SKILLS

The paired t-tests were first used to observe students' growth in SCT and SAST between their pretest and posttest scores. They indicated that the students of the MGI group made significant progress on both conceptual understanding ($t(57) = 15.54$, $p < .001$) and argumentation skills ($t(57) = 10.48$, $p < .001$). On the other hand, students in the traditional instruction group showed a significant improvement in the aspect of conceptual understanding ($t(56) = 7.81$, $p < .001$), but no significant improvement was found on argumentation skills ($t(56) = 1.68$, $p = .098 > .05$; Table 4).

Second, this study compared the relative effectiveness in improving students' conceptual understanding (posttest scores of SCT) between the two instructional methods using one-way ANCOVA to exclude the influence of covariance

TABLE 4. Students' scientific concept test and scientific argumentation skills test after treatments—paired t-test by treatments.

Group	Dimension	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	t-value	df	p
MGI[a] (n = 58)	SCT[b]	7.60	2.15	11.31	1.64	15.54	57	.001***
	SAST[c]	11.59	4.65	17.34	2.93	10.48	57	.001***
Traditional instruction (n = 57)	SCT	7.93	2.28	10.40	2.09	7.81	56	.001***
	SAST	12.86	4.27	13.70	3.92	1.68	56	.098

[a]MGI: Multi-genre digital Game-based Instruction
[b]SCT: Scientific Concept Test
[c]SAST: Scientific Argumentation Skills Test
***$p<.001$

(pretest scores of SCT) and examined the impact of the independent variable (instructional method). Similarly, the methods' effectiveness in improving students' argumentation skills was also examined with ANCOVA. Before the ANCOVA test, the homogeneity of regression slopes was performed to ensure that they were adhering to the underlying assumption so that following ANCOVA statistics can be continued.

TABLE 5. Analysis of one-way covariance (ANCOVA) on scientific concept test and scientific argumentation skills test.

Test	Treatment Group (No. of Students)	Mean Scores Before Adjustment	Mean Scores After Adjustment	F	p
SCT[a]	MGI[c] (58)	11.31	11.38	11.20	.001***
	Traditional instruction (57)	10.40	10.34		
SAST[b]	MGI (58)	17.34	17.59	55.053	.001***
	Traditional instruction (57)	13.70	13.44		

***$p<.001$
[a]SCT: Scientific Concept Test
[b]SAST: Scientific Argumentation Skills Test
[c]MGI: Multi-genre digital Game-based Instruction

The results of the homogeneity of regression slopes for both SCT and SAST showed no significance (SCT: $F(1, 111) = .050$, $p = .824 > .05$; SAST: $F(1, 111) = 3.549$, $p = .062 > .05$), which indicated that the assumptions of homogeneity were accepted; hence, the ANCOVA tests proceeded. Table 5 indicates a significant difference in SCT between the traditional instruction and MGI groups ($F(1, 111) = 11.20$, $p = .001 < .05$). The adjusted means of the SCT posttest scores showed that that of the MGI group (11.38) was higher than that of the traditional instruction group (10.34). For SAST, a similar result was also found. Its ANCOVA test showed a significant difference between the traditional instruction and MGI groups ($F(1, 112) = 55.053$, $p = .001 < .05$). The adjusted mean score of the SAST posttest of the MGI group (17.59) was higher than that of the traditional instruction group (13.44). In summary, the results of the ANCOVA indicate that MGI developed in this study significantly improved students' (MGI group) learning achievement in conceptual understanding and argumentation skills than those under traditional instruction (control group).

Although some studies have shown students' improvement in argumentation skills in traditional instruction [16], [17], some studies have suggested that it is challenging to enhance argumentation skills through traditional instruction only [18]. The results of the current study support the latter as it showed the lack of effectiveness of traditional instruction in improving the development of students' argumentation skills in the traditional instruction group.

Furthermore, this study extends the understanding that multi-genre digital games do not only promote students' learning motivation [37] as they can also help improve students' learning effectiveness. Moreover, this study adds knowledge to the use of digital game-based learning in elementary science [6], [31] by showing how digital game-based learning not only improved students' conceptual understanding but also enhanced students' argumentation skills in science learning in a way that traditional instruction by itself cannot achieve.

B. COMPARATIVE EFFECTIVENESS OF MGI AND TRADITIONAL INSTRUCTION ON STUDENTS WITH DIFFERENT ACHIEVEMENT LEVELS

For the second research question, students in both groups were separated by achievement level. Based on the students' level, the instructional effectiveness of the two instructional methods on all three achievement levels was compared.

ANCOVAs were applied to compare students' scores among the groups of students by level, one by one, in SCT and SAST. These analyses excluded the influence of covariance (pretest scores) and examined the difference of posttest by the effect of the independent variable, which is the instructional method. Notably, for some assumptions of homogeneity of regression slopes that are not appropriate for applying ANCOVA, the Johnson-Neyman technique was used to make intergroup comparisons. The results are reported in Table 6 and illustrated in Fig. 6.

1) HIGH-ACHIEVING STUDENTS

Upon conducting the tests of homogeneity of regression slopes for SCT and SAST, it was found that tests of homogeneity of SCT and SAST do not show significant differences (SCT: $F(1, 28) = .372$, $p = .547 > .05$; SAST: $F(1, 28) = .224$, $p = .640 > .05$). Because of this, covariance analysis was allowed to proceed.

As shown in Table 6, students of the MGI group have a higher adjusted posttest mean in SCT (12.19) than those of the traditional instruction group (11.69), but no significant difference ($F(1, 29) = 1.401$, $p = .246 > .05$) was found. Regarding SAST, the adjusted posttest mean (19.63) of the MGI group was higher than that of the traditional instruction group (15.49), and a significant difference ($F(1, 29) = 24.203$, $p < .001$) between MGI and traditional instruction

TABLE 6. Effectiveness of multi-genre digital game-based instruction vs. traditional instruction on students' conceptual understanding and argumentation skills in high-, medium-, and low-achieving groups.

Group	Test	Methods (No.)	Mean			F	p[a]
			Pre-	Post-	Post-(adjust-ted)		
High	SCT[b]	MGI[d] (16)	8.38	12.19	12.19	1.401	.246
		TI[e] (16)	8.38	11.69	11.69		
	SAST[c]	MGI (16)	13.60	19.38	19.63	24.203	< .001***
		TI (16)	15.75	15.75	15.49		
Medium	SCT	MGI (26)	7.80	11.31	11.35	1.781	.188
		TI (25)	8.04	10.76	10.71		
	SAST	MGI (26)	11.70	17.04	---	X_0= 26.27(*)f X_1= 19.48 X_2= 77.48	<.05*
		TI (25)	12.96	13.04	---		
Low	SCT	MGI (16)	6.50	10.44	10.59	21.93	< .000***
		TI (16)	7.31	8.56	8.41		
	SAST	MGI (16)	10.30	15.81	15.71	7.763	.009**
		TI (16)	9.80	12.69	12.78		

[a] ***$p<.001$, **$p<.01$, *$p<.05$
[b] SCT: Scientific Concept Test
[c] SAST: Scientific Argumentation Skills Test
[d] MGI: Multi-genre digital Game-based Instruction
[e] TI: Traditional instruction
[f] The test of regression homogeneity within groups shows a significant difference; the Johnson-Neyman technique was used.

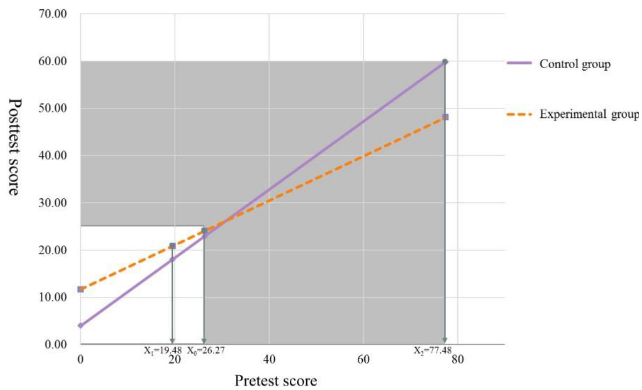

FIGURE 6. The cross point and significant difference point of the two regression lines for medium-achieving students of the control (traditional instruction) and experimental (Multi-genre digital Game-based Instruction) groups.

was found. These results indicate that, for high-achieving students, MGI can significantly improve their argumentation skills and help them develop their conceptual understanding equally well when compared to students in the traditional instruction group.

2) MEDIUM-ACHIEVING STUDENTS

The test of regression homogeneity within groups for SCT and SAST was conducted wherein it was found that the homogeneity test in SCT did not show a significant difference ($F(1, 47)$ =.297, p =.588 >.05), allowing the ANCOVA to proceed. Table 6 shows that no significance is found between MGI and the traditional instruction group, in terms of the learning on conceptual understanding ($F(1, 48) = 1.781$, p =.188>.05).

However, the test of regression homogeneity in SAST showed a significant difference ($F(1, 47) = 7.727$, p = .008 < .05), so the Johnson-Neyman technique was used instead. The result from the Johnson-Neyman analysis (Fig. 6) showed that the critical points of the pretest SAST scores at the significant level of.05 are 19.48 (X_1, (low)) and 77.48 (X_2 (high)), with the crossing point at 26.27 (X_0). Because the full mark of SAST is 25 points, this was left blank in Fig. 6 to represent a more accurate SAST score range. From this, we can restate further that students with pre-scores below 19.48 would gain significant growth in MGI than those who are in the traditional instruction group. In contrast, there is no significant difference for those with pre-scores above 19.48. After further checking the pre-scores of students, there were 47 of 51 students (92%) found to have pre-scores below 19.48, which indicates that for most students in the medium-achieving group, MGI is significantly more effective than traditional instruction.

In summary, for medium-achieving students, MGI shows equal effectiveness on students' learning on conceptual understanding yet higher effectiveness on students' learning of argumentation skills. Notably, this is similar to the findings on high-achieving students.

3) LOW-ACHIEVING STUDENTS

Tests of regression homogeneity within groups for SCT and SAST were conducted, and their results showed that both SCT ($F(1, 28) = 2.269$, p = .142 > .05) and SAST ($F(1, 28)$ =.011, p = .918 > .05) passed the homogeneity tests, thereby allowing the ANCOVA to proceed.

The results of the ANCOVA of SCT showed that the adjusted posttest mean of the MGI group (10.59) is significantly higher than that of the traditional instruction group (8.41; $F(1, 29) = 21.932$; p = .000 < .05). Also, for SAST, the adjusted posttest mean of the MGI group (15.71) is significantly higher than that of the traditional instruction group (12.78; $F(1, 29) = 7.763$, $p = .009 < .05$).

In summary, the results of this section extended the knowledge of how students of different achieving levels are affected by game-based learning [7], [11]. As shown in Table 6, the results indicated that MGI not only significantly enhanced students' argumentation skills of all three groups of students but also significantly improved low-achieving students' conceptual understanding when compared with their counterparts in the traditional instruction group. This showed that MGI not only improved high- and medium-achieving students' learning in argumentation; more remarkably, MGI effectively gave low-achieving students a new opportunity to learn better than with traditional instruction both in terms of conceptual understanding and argumentation skills.

C. STUDENTS' LEARNING EXPERIENCE IN USING MGI

1) EFFECT OF SITUATED GAMES ON STUDENTS' CONCEPTUAL UNDERSTANDING AND ARGUMENTATION SKILLS

All the 12 interviewed students reported that the situated game-based learning (UeBond) was helpful. This is supported by their positive response to Q2: "How does the UeBond game (situated game with adventure and role-playing genres) help you learn the concept of light?" For example, one low-achieving student (No.: S0915M-1) answered, "The animations [in the situated game] help me understand that when light enters the water, it refracts, which makes it look bent." He added, "I also learned that there are many examples of refraction in our daily life. The animations clearly explain the light's refraction." Several students (including S0902M-2 and S0903M-3) further responded that the questions presented in the situated game stimulated peer discussions, which helped clarify the concept of light. In addition, many students (including S0919F-2 and S0916F-3) reported that situated game-based learning made them understand abstract concepts more easily, given the diagrams, pictures, and video clips.

As to the learning of argumentation skills, 11 of the 12 students reported that the program helped them understand and learn scientific arguments by positively responding to Q3: "How does the UeBond game help you learn scientific argumentation?" For example, one student (S1025F-1), who is part of the low-achieving group, stated, "When you play the game, you have to help the characters in the story find solutions. As long as you follow the guidance and go along with the storyline and characters, you will be able to figure out what the claim and evidence are." Another student (S0903M-3) responded that the dialogues between the characters helped identify claims and evidence of argumentation. There was only one student (S1010M-2) who did not think the situated game was helpful, and it was because he felt confused at times by the information presented in the program, especially about argumentation.

From the above students' feedback, it is demonstrated that the situated game is capable of leading most students into a learning context and guiding them to achieve the learning goals. However, for some students who were not able to handle a vast amount of information at a time, a slight adjustment regarding content volume or a more individualized instructional design might help.

2) EFFECT OF COMPETITIVE GAMES ON STUDENTS' LEARNING

In response to Q4 (How do you like the Dodoya game?), most students (11 of 12) showed favor to the competitive game. Students stated that the Dodoya game helped them review science content and practice argumentation skills as well as gave them the motivation to keep learning so they would earn more points and rewards. One student (S0916F-S3) expressed disfavor toward the game as she considered the questions of the drills-and-practice game repetitive and lacking in variety. She was from the high-achieving group, likely eager to advance to more challenges after the success of responding to just a few questions. This suggests that a more customized design of the drills-and-practice system might be needed in future designs.

As to how the competitive game aids learning (Q5: How does the competitive game help your learning?), almost all students (11 of 12) showed favor to the competitive game, with one student (S0919F-2) saying, "The competitive game requires responses to questions in a certain period, which adds to the game's excitement." In terms of how the competitive game motivates sustained science learning, students (such as S1021F-2) mentioned that the competitive game provided them the opportunity to compete with their classmates to show how much they have learned, which made her look forward to her future classes. This highlighted the usefulness of adding a different game genre—a competitive game in this case—in providing positive learning incentives to motivate students' learning.

3) OVERALL REFLECTION

In answering Q1, "Based on your overall learning experience, do you think you were learning or playing in your previous science classes?", 7 of 12 students considered that they were learning. For example, one student (S0902M-2) commented, "It increased my knowledge, so I believe I was learning." The other five students thought they were learning and playing at the same time; for example, one student (S1025F-1) said, "(I) played games, to win points, I have to learn the content of light, so I will be able to answer questions and solve problems in the games." Notably, no student believed that MGI is solely for playing, which shows how the design of MGI is successful in adequately incorporating the attributes of learning and playing together, and, therefore, is likely to enhance their self-efficacy and learning effectiveness [26] through its adoption of multiple game genres into learning.

Concerning the helpful features of MGI asked in Q6, "Which part(s) of the program has/have helped your learning?", they expressed that they highly appreciated the narrative story with its well-organized structure. Students appreciated the use of situated games accompanied by experiment activities in instruction. They acknowledged that the game-based instruction helped them understand how to do experiments by receiving timely and useful guidance (S0903M-3).

As for Q7, "Which instructional approach (MGI or traditional instruction) would help you learn best, and why?" A total of 9 of 12 students expressed that MGI helped maintain their focus on learning and made the learning fun. For example, one student (S0918F-1) stated, "…Because the UeBond has a storyline and abundant learning content, we can apply what we learned when we were competing with our other classmates in the competitive game."

However, 3 of 12 students thought that although MGI was helpful, they expressed that traditional instruction would have made the explanations clearer.

In sum, the MGI courseware developed in this study combines genres of adventure, role-playing, and drill and practice. As it combines both the elements of situated and competitive games, MGI is capable of guiding students to achieve their learning goals as well as providing positive learning incentives to motivate students' learning. Through its adoption of multiple game genres into learning, its design allowed students to acknowledge that MGI is both for playing and learning, thus likely enhancing their self-efficacy and learning effectiveness [26]

The overall results show that MGI was well received by most of the students. Moreover, students acknowledged that MGI empowered their learning as they applied science knowledge to solve problems, thereby deepening their understanding of the unit of light. In the future, such specific feedback from students can serve as directions for developing future MGI courseware and designing better MGI approaches.

V. CONCLUSION

The potential benefits of using game-based instruction, which include attracting and sustaining student engagement and improving learning outcomes, have been suggested in previous research. Research designs often found that pedagogy needs to be flexibly designed based on the different requirements; thus, game-based instruction that involves various game genres should be agilely adapted according to the requirements for supporting students' learning. This study, therefore, developed Multi-genre digital Game-based Instruction (MGI) for elementary science lessons.

The results of the study are consistent with those of previous studies and show the effectiveness of MGI on students' science learning, including the aspects of conceptual understanding, argumentation skills, and overall learning experiences. Further analyses of students' learning performance among different achievement levels (high, medium, and low) showed that students of all levels had significantly higher performance in argumentation skills development under MGI than under traditional instruction. In addition, there is a significant improvement in the performance of low-achieving students concerning the learning of conceptual understanding. Low-achieving students, in general, do not necessarily lack in ability or attainment level but have a high likelihood of falling behind early on their education journey, continuing to perform poorly if no adequate and timely support is given to address their learning needs. These implications lead to this study's recommendation of incorporating game-based instruction in traditional instruction to close the achievement gap.

This study successfully developed the MGI model and courseware and showed its effectiveness in improving students' learning. The study attempted to control as many experimental factors as possible to minimize unintentional interferences and neglect; however, caution must be exercised in the interpretation of the study's findings. First, in this study, although the MGI and traditional instruction groups were all taught by the same teacher whose qualifications in terms of major (science), certification, and experience are similar to those of general elementary teachers, and considered that the MGI experience could be transferred to other class settings, we did not explore the comparative effectiveness when the groups are taught by teachers with different majors, educational backgrounds, and teaching experiences, which can be an important topic for future studies.

Second, based on previous studies, as indicated in the literature review and the findings of this study, this study supports the use of educational games as a powerful academic tool and MGI as an effective instructional approach in an actual classroom setting. Further research can be conducted to establish a more in-depth understanding of how single- and multi-genre digital games affect students' learning.

Third, because of our research emphases and restrictions involving young students' time and energy, this study did not measure students' growth resulting from the separated game genre (situated learning or competitive game). In future studies, more sophisticated evaluation techniques can be developed to measure the more in-depth learning process to gain a more profound understanding of how students learn and how each game genre affects students' learning in an MGI learning environment.

APPENDIX A
SAMPLE SCT ITEMS

The following are 2 samples out of the 13 SCT items.

1. By changing the angle between the two mirrors, different formations of images can be seen in the mirrors. What property of light is causing this phenomenon?
   (a) Traveling in straight lines
   (b) Reflection
   (c) Refraction
   (d) Scattering
   [Test concept: Reflection; correct answer: b]
2. Mom is watering flowers. What is likely to happen when sunlight passes through the water droplets in the air?
   (a) Water mist is generated.
   (b) A rainbow appears.
   (c) Water evaporates quickly.
   (d) No phenomenon will occur.
   [Test concept: Reflection and refraction; correct answer: b]

APPENDIX B
SAMPLE SAST ITEMS

SAST has five different themes as follows: (1) Temperatures of day and night; (2) Adsorption abilities of different materials; (3) Living things; (4) Dissolving sugar in water; and (5) Light travels in straight lines. Each theme included five items, with one item for each of Toulmin's argument components (claim, data, warrant, backing, and rebuttal). Sample items of the theme of "Dissolving sugar in water" relating to "claim" and "data" are shown below.

Theme 4: Dissolving sugar in water

> Put 50 g of granulated sugar in a cup filled with 100 ml of boiling water. What happens after stirring the mixture with a glass rod?
>
> Carmelo: The sugar will dissolve in the water.
> Jeremy: The sugar will become gas and evaporate into the air.
> Harden: The sugar will settle completely at the bottom of the cup.
>
> These three people have been arguing endlessly about this. Please help them solve this problem!

1. Based on their ideas, with whom do you agree?
   (a) Carmelo (b) Jeremy (c) Harden
   [Toulmin's argument component: Claim; correct answer: a]
2. (continuing from the previous question…) Which of the following evidence best supports your idea?
   (a) The water tastes sweet.
   (b) Granulated sugar particles can be seen at the bottom of the cup.
   (c) You can smell the sweetness when near the cup.
   (d) The sugar water was weighed and was 100 g.
   [Toulmin's argument component: Data; correct answer: a]

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