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Effects of Technology-Enhanced Board Game in Primary Mathematics Education on Students' Learning Performance

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Abstract: In primary schools, mathematics is a fundamental and an important subject since mathematical concepts and skills are useful to address life and professional problems. Nevertheless, many mathematical concepts are abstract to primary students that may possibly cause them to learn mathematics with poor learning motivation and performance. To address this problem, it is important to promote students to review and apply mathematical concepts after they learn. In traditional mathematics classrooms, teachers usually assign exercises to students for conducting review and application activities after formal mathematics instructions. However, such learning activities may tend to make students less motivated to conduct them and further negatively affect their learning performance. Therefore, this study adopted a technology-enhanced board game to support teachers and students to conduct prime factorization education in traditional mathematics classrooms. The aim of this study is to apply the proposed board game to facilitate students to review and apply prime factorization concepts after traditional classroom learning, and further enhance their learning performance. To evaluate the proposed approach, 22 primary students were allocated to an experimental group and a control group to participate in an experiment. The experimental group was supported by the board game approach to conduct review and application activities after traditional mathematics learning, while the control group utilized a traditional exercise approach to conduct review and application activities after traditional mathematics learning. The research results revealed that the proposed approach not only promoted the students' learning achievements in prime factorization education, but also improved their learning motivation and attitude.

Keywords: mathematics education; board game; prime factorization; primary education; quality education

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1. Introduction

Mathematics is a crucial subject to students since it is an important foundation for other professional fields such as artificial intelligence and cryptography [1]. Moreover, mathematical concepts and skills are also useful to address life problems [2]. Nevertheless, most mathematical concepts are related. This means that if students can learn basic mathematics well, it can improve their learning performance in learning advanced mathematics in the future [3]. Therefore, mathematics education in primary schools is important to teachers and students. However, several mathematical concepts are abstract to primary students that may possibly cause them to learn mathematics with poor learning motivation and performance [4].

According to the report of trends in international mathematics and science study, the mathematics ability of Taiwanese primary students is better than the international average. However, Taiwanese primary students have poorer learning attitudes towards mathematics education. Szabo et al. indicated that mathematics education not only focuses on giving students a basic understanding of mathematical concepts, but also gives students the opportunity to review and apply mathematical concepts as they learn [5]. Moreover, the shift in mathematics education from basic understanding to application has had a significant impact on students' learning motivation and achievement [6].

Therefore, in conventional mathematics education, teachers usually assign exercises to facilitate students to review and apply mathematical concepts they have learned. However, such learning activities may tend to make students less motivated to conduct them [7]. To address this problem, past studies proposed game-based learning approaches, such as board games, to encourage students to review and apply mathematical concepts while playing. Hendrix, Hojnoski, and Missall adopted a board game to facilitate students' counting ability [8]. The research result indicated that the approach can enhance students' counting ability and further enhance their mathematical skills. Russo, Bragg, and Russo stated that board games are able to be used by teachers for training students' mathematical skills and problem solving ability in mathematics classes [9]. Moreover, Bayeck indicated that board games are useful to promote students' interactions and further facilitate their mathematical thinking skills and social ability [10].

Prime factorization is a core unit in primary mathematics education in that it is a critical foundation to further learn algebra or cryptography. However, when students learn about prime factorization, the learning performance of most students, such as learning attitude, learning motivation, and learning achievement, is often not as good [11]. Therefore, board games are one possible approach to improve students' learning performance in prime factorization. Nevertheless, traditional board games still have some possible risks during students' play process. The first is that it is difficult for teachers to monitor each student's play status and assist all students in playing games simultaneously [12]. Second, students may apply wrong concepts or calculate incorrect results unaware while playing games, which may further cause negative effects on mathematics learning [13].

As mentioned above, the aim of this study is to apply a technology-enhanced board game to facilitate primary teachers and students to conduct prime factorization education in traditional mathematics learning environments. The board game is used to support students in reviewing and applying the concepts of prime factorization after learning. To evaluate the effectiveness of the proposed approach, an experiment was conducted in mathematics classes in a Taiwanese primary school.

The remainder of this paper is organized as follows. Section 2 presents the literature review of this study. The architecture and implementation of the board game are introduced in Section 3. The experiment design and result evaluation are shown in Sections 4 and 5. Finally, the discussion and conclusion are presented in Section 6.

2. Literature Review

2.1. Prime Factorization Education

Prime factorization is related to the concepts of factors, composite numbers, prime numbers, etc. Therefore, prime factorization concepts are complex and abstract for most primary students, which may lead to poor learning attitude and low learning motivation of students. Nevertheless, prime factorization learning is important to students in mathematics education in that prime factorization concepts are fundamental for students to learn algebra or cryptography. To address the problem, several studies proposed various approaches to enhance students' learning performance in prime factorization. Chen and Wang [14] used a board game to support the instruction of highest common factor and least common multiple concepts. The result pointed out that the use of the board game in learning situations can attract students' attention, enhance learning motivation, and improve learning achievement. Pradhan [15] taught the abstract mathematical concepts of prime numbers and composite numbers by using drawing aids. Through a series of guided activities, students were facilitated to observe and reflect, and then they learned the mathematical concepts of prime factorization. Tucker-Raymond, Lewis, Moses, and Milner [16] used the game Flagway to train students' arithmetic ability and prime factorization ability. Since the game requires students to form a group and conduct competitions, it not only trains students' mathematical ability but also improves students' teamwork and social communication skills.

Although game-based learning approaches can facilitate prime factorization education, Nousiainen, Kangas, Rikala, and Vesisenaho mentioned some problems with traditional game-based learning [17]. For example, in order to engage students in learning in each game, teachers should provide suitable supports and guidance to students. Nevertheless, there are actually 20 to 30 students in a class, and it is difficult for teachers to monitor and guide each student's learning status and misconceptions during and after each game [18].

2.2. Board Games in Education

In recent years, many studies proposed and investigated the effects of educational board games on students' learning performances in different subjects [19–22]. Smith and Golding [19] discovered that students' mathematical thinking skills are significantly improved after playing board games. Kim and Park [20] adopted a board game to deliver the concepts of artificial intelligence to students and foster their computational thinking ability. Dziob [21] applied a physical board game to assess students' learning performance. The results indicated that the approach can enhance students' learning attitude, motivation, and achievement, and reduce students' anxiety about learning assessment. Li, Yang, and Xue [22] used a chemical board game to facilitate students to learn chemical knowledge. The investigated results showed that the use of the board game can enhance students' engagement and belief. Moreover, the use of the board game can also promote students' interactions and discussions.

According to the past studies, board games are a learning tool that can be used to support teachers in proposing a game-based learning approach for engaging students in learning and reviewing subject concepts. The use of board games can not only improve students' learning motivation and learning achievement, but also enhance students' learning retention and social interactions. Nevertheless, the literature also mentioned that it is important for teachers to monitor each student's learning status during the learning process. In traditional board games, teachers obviously are not able to monitor all students' learning status at the same time. Moreover, traditional board games also cannot provide guidance to each student for teachers.

2.3. Review and Application in Mathematics Education

In traditional primary mathematics classes, students are usually trained by teachers to learn how to quickly calculate results. After such learning, most students can only remember and understand the concepts. Agarwal and Bain also indicated that most students cannot learn high-order thinking skills and enhance their learning performance in traditional mathematics education [23]. To address this problem, past studies indicated that review and application are important learning activities to enhance students' learning performance in mathematics education [24,25]. Through participating in review activities, students are able to become more proficient with related concepts and further internalize the concepts into individual knowledge. Furthermore, teachers should also provide opportunities for students to apply mathematical concepts to solve problems. By assigning application activities, students have to use and connect the relevant concepts they have learned to find solutions for completing the activities. McNelles, Kaliazine, Scott, and Gendron [26] presented that students' mathematical learning performance is positively correlated with their ability to apply the mathematical concepts they have learned.

As mentioned above, this study applied a technology-enhanced board game to support teachers in developing review and application activities for students in traditional mathematics learning environments. By playing the board game, students are able to review and apply prime factorization concepts according to the rules of the board game and compete with their peers to become the winner. Students' learning performance can be thus enhanced by engaging in the game-based review and application activities. The following research questions were proposed to evaluate the effectiveness of the proposed approach.

1. Is there any difference between the traditional exercise approach and the board game-supported exercise approach in terms of students' learning achievement in prime factorization learning?
2. Is there any difference between the traditional exercise approach and the board game-supported exercise approach in terms of students' learning attitude in prime factorization learning?
3. Is there any difference between the traditional exercise approach and the board game-supported exercise approach in terms of students' learning motivation in prime factorization learning?

3. Technology-Enhanced Prime Factorization Board Game

The technology-enhanced board game was applied in this study to support teachers in conducting prime factorization education in traditional learning environments. The board game is a card game developed using mobile and sensor technologies [27]. The architecture of the board game is shown in Figure 1. The board game system consists of 40 RFID cards, a board game application, a cloud database, and a learning analytic website.

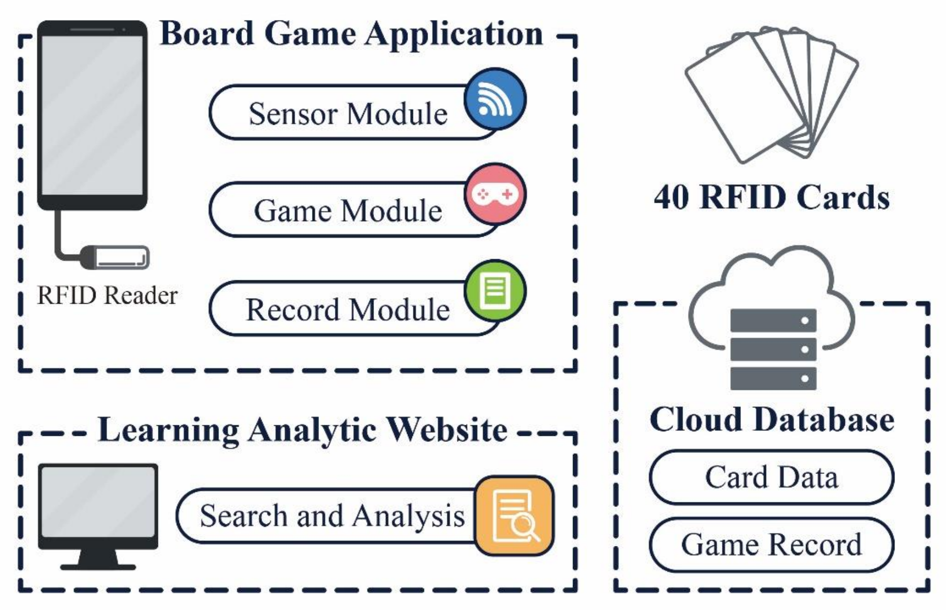

Figure 1. System architecture.

To play the board game, students firstly set a deck of 40 RFID cards on a table and prepare a mobile device with the board game application. Each card presents a composite number or a prime factor, as show in Figure 2. Each game is set to support 2 to 3 students to play together. After the cards are shuffled, each student is dealt 6 or 9 cards depending on whether 3 or 2 students are participating in the game. Moreover, 4 cards are turned over face up from the remaining deck and placed in the layout, as shown in Figure 3. During the game process, students have to review and apply prime factorization concepts to capture a card from the layout by using individual hand cards. The capture rule is to require students to determine whether the cards turned over on the table are the same as the cards in the hand, or whether the cards turned over on the table and the cards in the hand are a composite number and a prime factor. If a capture is successful, the student wins the captured card and scores. If a student's individual hand cards cannot capture any card from the layout, the student cannot score and has to leave an individual hand card as a new layout card. Whether or not a student successfully captures a card from the layout, it is then the next player's turn.

Figure 2. Faces of 40 RFID cards.

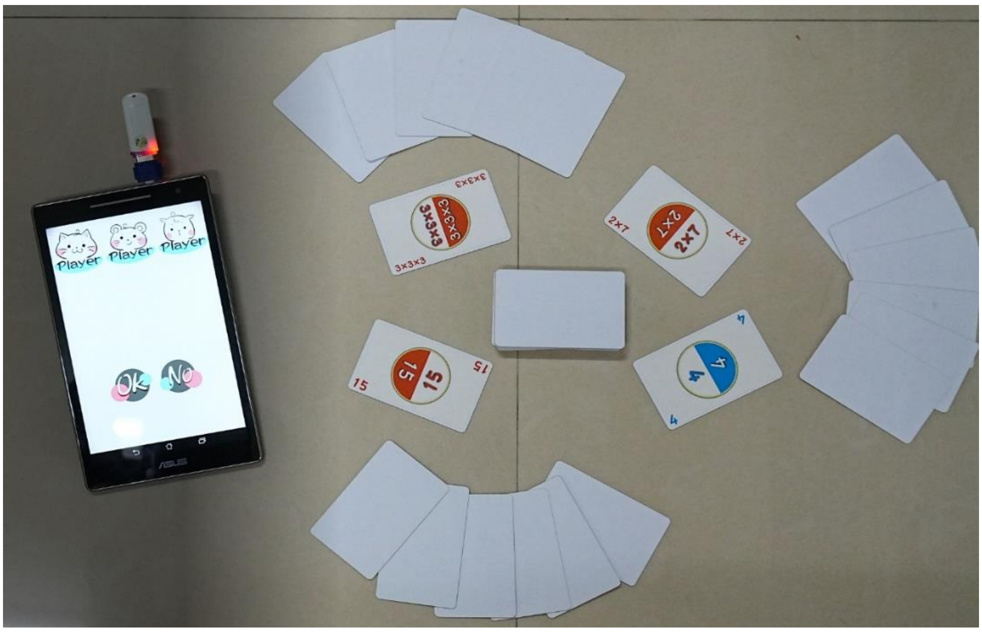

Figure 3. The board game settings.

To support students in playing the board game, the board game application is used to navigate and guide students to play the game. The sensor module of the board game application is used to detect each RFID card played by students in the game. The game module is developed to control the game process, including assisting student in determining whether card captures are correct or not. The record module is used to record each student's play status, including incorrect capture information. All cards' information and game records are stored in the cloud database.

4. Experiment

The purpose of the board game-supported prime factorization learning approach is to promote teachers and students to conduct review and application activities after traditional classroom learning. This study aims to apply the proposed approach to engage students in learning prime factorization concepts and further assist them in reviewing and applying the concepts they have learned. To evaluate the effect of the proposed approach, the experimental design and settings are described as follows.

4.1. Participants

The participants were 6th grade students (aged 11–12 years) from a Taiwanese primary school in southern Taiwan. Twenty-two students (10 boys and 12 girls) were invited and assigned to two groups. Eleven students were allocated to a control group and eleven to an experimental group, respectively. For the control group, students participated in traditional prime factorization classes and further conducted exercises to review and apply prime factorization concepts they had learned. For the experimental group, students engaged in traditional prime factorization classes and further used the board game to review and apply prime factorization concepts they had learned. The students of the two groups were taught by a teacher with more than 20 years of teaching experience in primary mathematics education. This study did not arrange a traditional board game intervention in this experiment since the technology-enhanced board game retains the features of the traditional board game.

4.2. Procedure

To evaluate students' learning performance in using the proposed board game to support traditional prime factorization classes, a quasi-experiment was conducted. The experimental procedure is shown in Figure 4. The length of the experiment was 2 weeks (6 classes). In the experiment, the students of the two groups were firstly asked to take a learning attitude questionnaire and a prime factorization prior knowledge test in the first class. After the two pre-tests, the teacher further conducted prime factorization instructions for the students of the two groups via 3 classes. Following that, the teacher utilized one class to facilitate all students to review and apply prime factorization concepts they had learned. The students of the control group conducted traditional exercises to review and apply prime factorization concepts and the students of the experimental group used the proposed board game to conduct the review and application activity. Finally, the students of the two groups were asked to take a learning attitude questionnaire, learning motivation questionnaire, and a learning achievement test.

4.3. Instrument

This study used four measuring tools to evaluate the effects of the proposed approach on students' learning performance, including a learning attitude questionnaire, a learning motivation questionnaire, a prior knowledge test, and a learning achievement test.

The learning attitude questionnaire was proposed by Hwang and Chang [28]. The questionnaire contains 7 items, and uses a 5-point Likert rating scale (1: totally disagree to 5: totally agree) to evaluate students' learning attitude regarding participating in prime factorization classes, such as "The course is valuable and worth studying" and "I would like to know more about the learning targets". The questionnaire has been used in many studies and has shown good reliability [29–31]. In this study, the overall Cronbach's alpha value of the questionnaire was 0.938. The reliability of this questionnaire in this study was tested from the answers of 40 students [32].

The learning motivation questionnaire is amended from the intrinsic value scale of Motivated Strategies for Learning Questionnaire (MSLQ) developed by Pintrich and De Groot [33]. The questionnaire consists of 9 items with a 5-point Likert rating scale ranging from 1 (totally disagree) to 5 (totally agree) to evaluate students' learning motivation, for instance, "I prefer class work that is challenging so I can learn new things", "It is important for me to learn what is being taught in this class", and "I think that what we are learning in this class is interesting". Many studies have used the questionnaire and revealed good reliability of the questionnaire [34–36]. The Cronbach's alpha value of the questionnaire was 0.957. The Cronbach's alpha value of this questionnaire in this study was tested from the answers of 40 students [32].

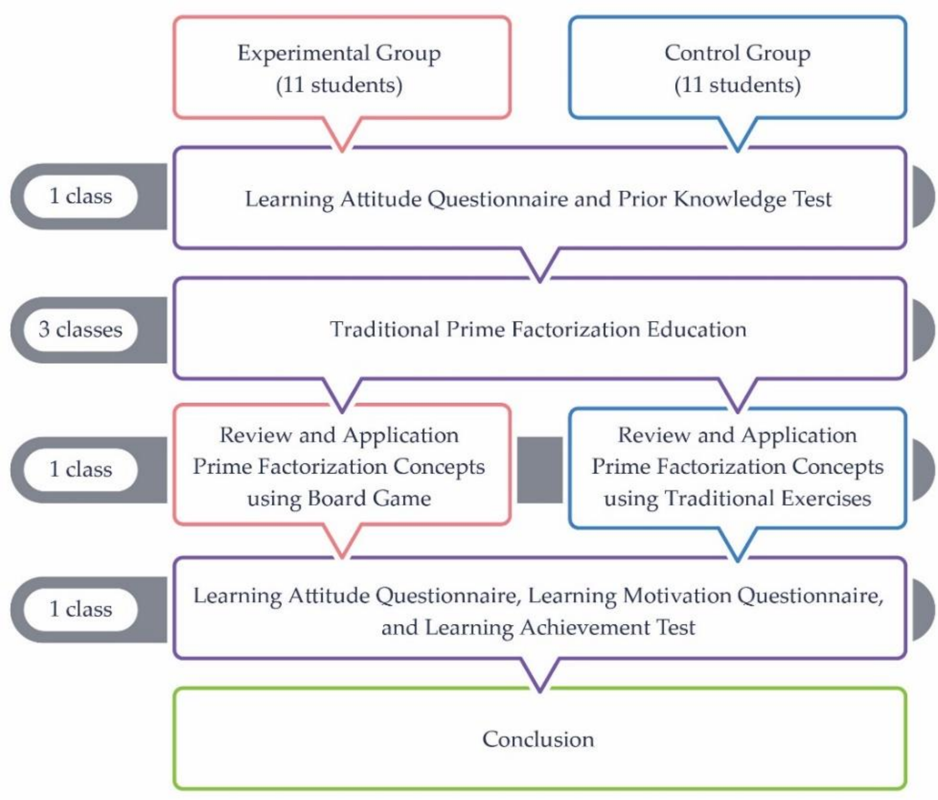

Figure 4. Experimental procedure.

The prior knowledge test and learning achievement test were related to prime factorization concepts and administered as paper-and-pencil tests with a maximum score of 100. The items of the two tests were developed by two teachers who had taught primary mathematics for over 10 years and the two tests were different.

5. Results

5.1. Prior Knowledge Analysis

In this analysis, a prior knowledge analysis was performed to investigate whether the students of the two groups had an equivalent prior knowledge level before participating in the experiment. To conduct this analysis, an independent sample *t*-test was used to evaluate the prior knowledge tests of the students from the two groups. As tabulated in Table 1, the mean value and standard deviation of the students in the control group were 57.72 and 30.11. Those values of the students in the experimental group were 66.36 and 30.82. Then, the homogeneity of variance was assessed by Levene's test, whose result showed that the within-group variances were considered equal ($F = 0.017$, $p = 0.514 > 0.05$). The result of the independent sample *t*-test showed no significant difference between the two groups with regard to the prior knowledge of prime factorization ($t(20) = 0.665$, $p = 0.514 > 0.05$).

Table 1. The independent sample *t*-test result of the prior knowledge for the two groups.

Group	N	M	SD	*Levene*'s Test		*t*-Test	
				F	*p*	*t*	*p*
Experimental Group	11	66.36	30.82	0.017	0.898	0.665	0.514
Control Group	11	57.72	30.11				

5.2. Learning Achievement Analysis

To investigate the difference of the learning achievement depending on the traditional exercise approach and the board game-supported exercise approach between the two groups, a one-way ANCOVA was performed after neutralizing the effect of the students' prior knowledge. The assumption of homogeneity of the regression slope ($F = 4.217$, $p > 0.05$) was not violated, indicating that the ANCOVA was suitable to perform. Table 2 shows the ANCOVA result of the learning achievement for the two groups. It was found that the average learning achievement score of the experimental group was significantly higher than that of the control group ($F(1,19) = 4.647$, $p = 0.044 < 0.05$). The result reveals that the board game-supported exercise approach in traditional prime factorization classes is more beneficial to students than the traditional exercise approach in terms of learning achievement.

Table 2. The ANCOVA result of the learning achievement for the two groups.

Group	N	M	SD	Adjusted M	Adjusted SD	*F*	*p*
Experimental Group	11	94.09	6.64	92.55	5.81	4.647	0.044 *
Control Group	11	73.18	29.85	74.72	5.81		

* $p < 0.05$.

5.3. Learning Attitude Analysis

In this analysis, an independent sample *t*-test was firstly used to investigate whether the students of the two groups had an equivalent learning attitude before participating in the experiment. As shown in Table 3, the mean value and standard deviation of the students in the control group were 3.58 and 0.81. Those values of the students in the experimental group were 4.18 and 0.55. Then, the homogeneity of variance was assessed by Levene's test, whose result showed that the within-group variances were considered equal ($F = 1.32$, $p = 0.264 > 0.05$). The result of the independent sample *t*-test revealed no significant difference between the two groups with regard to the learning attitude before undertaking the experiment ($t(20) = 2.01$, $p = 0.058 > 0.05$).

Table 3. The independent sample *t*-test result of the learning attitude for the two groups before the experiment.

Group	N	M	SD	*Levene*'s Test		*t*-Test	
				F	*p*	*t*	*p*
Experimental Group	11	4.18	0.55	1.32	0.264	2.01	0.058
Control Group	11	3.58	0.81				

To investigate the difference of the learning attitude depending on the two approaches between the two groups, a one-way ANCOVA was further conducted to neutralize the effect of the scores of learning attitude pre-questionnaire. The assumption of homogeneity of the regression slope ($F = 0.301$, $p > 0.05$) was not violated, indicating that the ANCOVA was suitable to conduct. Table 4 shows a significant difference between the two groups in the learning attitude post-questionnaire ($F(1,19) = 16.156$, $p = 0.001 < 0.05$). This means that the use of the board game-supported exercise approach in traditional prime factorization classes affected the students' learning attitude positively. To be more specific, students who engaged in the proposed prime factorization learning approach significantly surpassed those who engaged in the traditional prime factorization learning approach in terms of learning attitude.

Table 4. The ANCOVA result of the learning attitude for the two groups.

Group	N	M	SD	Adjusted M	Adjusted SD	*F*	*p*
Experimental Group	11	4.28	0.42	4.13	0.10	16.156	0.001 *
Control Group	11	3.37	0.51	3.52	0.10		

* $p < 0.05$.

5.4. Learning Motivation Analysis

In this analysis, a learning motivation analysis was employed to evaluate whether the students of the two groups had an equivalent learning motivation after participating in the experiment. To conduct this analysis, an independent sample *t*-test was used to evaluate the learning motivation questionnaire of the students from the two groups. As tabulated in Table 5, the mean value and standard deviation of the students in the control group were 3.43 and 0.78. Those values of the students in the experimental group were 4.39 and 0.41. Then, the homogeneity of variance was assessed by Levene's test, whose result showed that the within-group variances were considered equal ($F = 3.55$, $p = 0.074 > 0.05$). The result of the independent sample *t*-test showed a significant difference between the two groups with regard to the learning motivation after participating in the experiment ($t(20) = 3.59$, $p = 0.002 < 0.05$).

Table 5. The independent sample *t*-test result of the learning motivation for the two groups.

Group	N	M	SD	*Levene*'s Test		*t*-Test	
				F	*p*	*t*	*p*
Experimental Group	11	4.39	0.41	3.55	0.074	3.59	0.002 *
Control Group	11	3.43	0.78				

* $p < 0.05$.

6. Discussion and Conclusions

This study proposed a board game-supported learning approach capable of supporting students' prime factorization learning after traditional classroom learning. The board game provides a gamification situation that encourages students to review and apply prime factorization concepts. An experiment was also conducted in traditional prime factorization classes to evaluate the effectiveness of the proposed approach. The experimental results verified that the proposed board game-supported learning approach provided effective supports for both teacher and students to conduct prime factorization learning. The students in the experimental group exhibited higher learning attitude, learning motivation, and learning achievement as they participated in the proposed learning approach.

The experimental results of this study support the argument proposed by Hwa, who stated that the adaptation of appropriate learning tools is a useful approach to positively motivate students' learning and affect their attitude in traditional mathematics learning environments [7]. Regarding the students' learning achievement, Zainuddin, Shujahat, Haruna, and Chu indicated that students who learn with gamification learning tools in traditional classes can enhance their engagement and further improve their learning achievement [37]. They emphasized that comparing to paper-based exercises, students perceived gamified e-exercises in a formal learning context as fun, motivating, and engaging. They also presented that through the design of competitions, feedback, and scores in a gamification learning tool, it makes learning fun and further encourages students' learning performance in learning. The findings of this study also suggested that the abovementioned factors in a board game implementation are important in that the factors provide visible incentives for enhancing students' learning performance. Furthermore, Hussein, Ow, Elaish, and Jensen noted that game-based learning approaches are useful to promote students' learning performance in mathematics education [38]. Van Eck has also stated that educational games have positive effects on students' learning performance since the learning takes place in a meaningful context [39].

From the view of the board game design, the board game engages students in competing with peers that can motivate students to achieve learning aims [40]. Immediate reward is also a useful design to enhance students' learning performance. In the proposed board game, the score mechanism encourages students to review and apply prime factorization concepts to gain a higher score [41]. Moreover, immediate feedback is important to improve students' learning motivation and achievement during their learning process [42]. The proposed board game can provide immediate feedback to support and guide students when they apply wrong concepts or calculate incorrect results. Furthermore, the proposed board game requires students to play face to face. Past studies indicated that face to face interaction is significant to students for engaging in a meaningful learning process [43,44]. In addition, the proposed board game is a cyber physical system that includes a virtual board game application and real hand cards. The literature also pointed out that cyber physical systems are useful to enhance students' learning motivation and further improve their learning achievement [45,46].

In summary, the main contribution of this study is to propose an attractive review and application approach to support prime factorization instructions in traditional mathematics classes. In addition, some limitations have to be noted in this study. First, as a result of primary school semester considerations in Taiwan, this study did not conduct a random selection to select the students to participate in the experiment. Second, the sample size was not large, so the results could not be generalized to the possible learning performances in different contexts and applications. Furthermore, since the number of samples is small in this study, the statistical power may be insufficient. Nevertheless, an independent *t*-test and ANCOVA is still a robust approach to support the analyses in this study [47,48]. Future studies should implement large random selections and conduct various analyses when applicable. In addition, this study was conducted in an Asian country. The research settings and results might not be directly applicable to mathematics classes in other countries with different cultures, educational policies, or learning environments. Furthermore, future studies can conduct a three-group experimental design (traditional exercise, traditional board game-supported exercise, and technology-enhanced board game-supported exercise) to further evidence the effectiveness of the proposed approach. Finally, longitudinal data should also be collected to investigate the retention power between the above three interventions and learning achievements.

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