Education and Information Technologies
https://doi.org/10.1007/s10639-023-11708-6

Design and evaluation of a remote synchronous gamified mathematics teaching activity that integrates multi-representational scaffolding and a mind tool for gamified learning

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Received: 25 July 2022 / Accepted: 1 March 2023

Abstract
Gamified learning is an instructional strategy that motivates students to learn, and the use of multiple representations assists learning by promoting students' thinking and advanced mathematical problem-solving skills. In particular, emergency distance learning caused by the COVID-19 pandemic may result in a lack of motivation and effectiveness in learning. This study designed an online gamified learning activity incorporating multi-representational scaffolding and compared the differences in the learning achievement and motivation for the gamified activity and general synchronous distance learning. In addition, for the group that conducted the gamified learning activity, we measured the participants' flow, anxiety, and emotion during the activity. A total of 36 high school students participated in the experiment. The results indicated that the gamified learning activity was not significantly effective in terms of enhancing learning achievement. In terms of learning motivation, a significant decrease in motivation was found for the group using general synchronous learning, while a significant increase in motivation was found for the group using synchronous gamified learning. This indicates that despite the negative impact of the pandemic on learning, gamified learning still enhances students' learning motivation. The results of flow, anxiety, and emotion showed that the participants had a positive and engaged experience. Participants provided feedback that the multi-representational scaffolding facilitates learning.

Keywords Gamification · Game-based learning · Multi-representational scaffolding · Synchronous learning · Distance learning

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Published online: 24 March 2023

1 Introduction

Traditional mathematics (math) teaching is often lecture-based when teaching students standard problem-solving steps, allowing students to practice repeatedly to become familiar with problem solving steps for mathematical problems, which is less effective for improving students' ability to analyze problems and solve complex problems (Dagoc & Tan, 2018) and fails to motivate students to learn (Safapour et al., 2019). Because math courses often require complex calculations, many students view math as difficult and time-consuming, and requiring a high degree of patience, so they are not interested in math courses (Guven & Ozcelik, 2017; Tarasova & Savvina, 2019). Some students do not have poor math skills, but rather have anxiety about learning math (Ashcraft & Kirk, 2001), and math learning anxiety can lead to students not wanting to learn math and can reduce their effectiveness in learning math (Lukowski et al., 2019; Foley et al., 2017). As a review study by Balt et al. (2022) mentions, this is a vicious cycle. Students will become more anxious because of their poor achievement in math, and this anxiety will lead to students avoiding math, which in turn will lead to students not improving their math skills. Fortunately, using a variety of instructional strategies to reduce math anxiety has the opportunity to break this vicious cycle.

The impact of the COVID-19 pandemic has forced many schools to switch to synchronous remote education, which is also called emergency remote education (Bozkurt et al., 2020). In emergency remote education, there are more issues to be covered, such as the psychological stress brought by the pandemic itself, the loss of face-to-face communication, and so on (Bozkurt et al., 2020; Winter et al., 2021). Remote education is more accessible than traditional classroom education and is not limited by the location of teachers and students and can be accessed from all over the world (Ragusa & Crampton, 2017). However, in emergency distance learning situation, teachers may often lack the time and experience to design online courses carefully, and students face challenges such as distractibility, moodiness, and long periods of persistence and attention, which can influence their learning experience and engagement (Donham et al., 2022). Other studies have also found that low interaction, technological limitations, and deconstruction resulting from emergency distance learning have significant effects on distance education effectiveness (Tulaskar & Turunen, 2022). In distance education, students' eyes are easily tired and the demand for network equipment and high internet bandwidth (Xue et al., 2020). However, in the more severe years of the pandemic, the distance learning policies that resulted from the pandemic accelerated the adoption of technology as an educational tool, and despite the limitations of distance learning, the advantages of developing examples of distance learning were recognized, and the various instructional methods used in this adaptation process gave teachers and students the opportunity to grow together as lifelong learners (McBee et al., 2022). Synchronous distance learning has also become a common teaching method in the post-pandemic era. Among the various strategies, gamified learning is one of the potential strategies to promote learners' motivation. Long remote courses can lead to students' inability to focus on remote courses but using gamified learning in the classroom can engage and motivate students (Glover, 2013) and increase student engagement in the course (Hanus & Fox, 2015; Huang & Hew, 2015).

Gamified learning enhances students' motivation to learn (Hamari et al., 2014; Zainuddin et al., 2020). In gamified learning, teachers blend game elements into classroom instruction, allowing students to work in groups, and interact and compete for points on learning tasks, while the process promotes motivation, social interaction, and reflective behaviors to achieve tasks (Manzano-León et al., 2021).

Gamification has been widely used to design better instructional activities that aim to increase student attention, motivation, engagement, flow, and other positive experiences (Oliveira et al., 2020). A review by Arufe-Giráldez et al. (2022) found that gamification, when combined with other teaching modes, can have a positive impact on intrinsic motivation and self-directed learning. The review also found that many studies have researched the combination of gamification with social networks, virtual reality, augmented reality and mobile appliances. Suitable gamification mechanisms with technology-presented multimedia can reduce students' anxiety in learning mathematics (Coffland & Huff, 2022). Gamified learning activities with various technologies such as mobile technology, augmented reality (AR) and virtual reality (VR) are increasingly discussed. However, considering the features and uncertainties of distance learning, it is necessary to consider the technology-oriented gamification strategies that can be most easily adopted and effective for teachers and students. For example, although VR allows learners to experience immersive virtual worlds, research suggests that the use of VR must consider cost, ease of use, technical challenges, and ethics (Imogen et al., 2020). Limitations on the VR experience are that users may feel disoriented, dizzy, or fearful of colliding with real objects, and must be used in a safe range (Rauschnabel et al., 2022). Therefore, in distance learning, it is necessary to consider the students' and teachers' network environment and hardware and software, ease of use, and security issues to adopt technology or media. Besides, the mechanisms and rules of gamified learning may cause students cognitive load or learning anxiety (Spieler et al., 2020). Therefore, tools are needed to reduce the cognitive load imposed by gamified learning, of which mind tools are a possible option (Teemueangsa, & Jedaman, 2021; Chen et al., 2022). At this point, the use of mind tool designed to support gamified learning activities has potential for distance learning and is the tool used in this study to provide scaffolding support for gamified learning activities.

Mind tools are digital applications such as databases, web-based tools, and multimedia presentation tools that enable students to learn content in a variety of different assistive ways (Jonassen & Carr, 2020; Russell, 2015). Mind tools serve as learning aids for students to think more effectively (Jonassen, 1995) and can improve attention and learning achievement, and reduce stress in the classroom (Diamond et al., 2019; Nesbitt & Farran, 2021). Also, mind tools are carriers that allow teachers to provide scaffolding. Wood et al. (1976) and Maryam et al. (2019) referred to the functions that scaffolds have, including learning guidance, learning load reduction, learning process control, and demonstration. Hou and Keng (2021) proposed a dual scaffolding framework in which peer interaction is used as a peer scaffold and technology is used to provide cognitive scaffolding during gamified learning in order to facilitate peer interaction, cognitive thinking, and collaborative problem solving.

In math and science subject learning, the way content is represented has a significant impact on learning. Berthold and Renkl (2009) used both textual and graphical representations of mathematical knowledge and found that for representational knowledge (e.g., formulas), using textual representations helped learning, but that using both textual and graphical representations helped students integrate and understand complex knowledge. Mnguni's (2014) research suggests that transforming concepts that are difficult to observe with the naked eye (such as chemical equation of glucose metabolism) into a visual representation in science learning can help students construct knowledge. A review by McElhaney et al. (2014) also pointed out that dynamic visualizations (e.g., videos, gifs) help students construct knowledge, and that the simultaneous use of multiple representational scaffolds does not necessarily have a dual effect on learning achievement but is useful for the construction of knowledge in students' cognitive processes. Wang et al. (2018) suggested that the use of pictures or video representations of scaffolding can be useful for learning scientific knowledge or abstract knowledge, but the presentation needs to take into account the students' familiarity with the presentation. In their study, Liang and She (2021) used both a text scaffold and a text-and-picture scaffold to support students in solving mathematical problems. Their findings showed that either scaffold could help students learn mathematics, but the use of multiple representation scaffolds was more effective in helping students solve mathematical problems. In the design of multiple representation scaffolds, Rau and Matthews (2017) suggested that multiple representation scaffolds should not be presented in multiple ways, but should be linked to construct concepts, and that poorly designed multiple representations can cause cognitive load and cognitive errors for students. In an emergency remote education context, it is worth exploring whether the combination of multiple representational scaffolds and gamification can help learners' cognition and motivation in mathematics learning.

This study used the Mind Tool for Gamified Learning (MTGL) (Chen et al., 2022, in press) for gamified learning and multiple representations of scaffolding. MTGL is a web application that runs on mobile devices. It can present gamified mechanics such as real-time checking of scores, points, leaderboards, and presents different representations of scaffolding including text, images, and videos.

In this study, the teaching content was "three-dimensional geometry and surface area.“ The researcher designed three types of representational scaffolds. The presentation of geometric knowledge in multiple representations has been shown to be an effective design for mathematical learning (Gero & Reffat, 2001; Berthold & Renkl, 2009). A variety of common mathematical representations, including 2D scaffolding or 3D scaffolding used in geometry instruction, are useful for learning (Hoffmann & Németh, 2021; Choo et al., 2020; Harron et al., 2022). The multiple representational scaffolding designed for this study includes a "textual description of geometric composition,“ a "2D perspective drawing,“ and a "3D geometric model presentation video.

The design of this study was expected to help students improve their mathematical problem-solving skills and to promote collaborative problem solving with peers through gamification. It was also expected that the gamified mechanism may increase learners' motivation to learn mathematics, reduce their anxiety, help them to achieve flow, and promote their learning achievement. Few studies have explored the design of multi-representational remote gamified learning activities, and few studies have explored the learning achievement, flow, motivation, and anxiety of learners in such activities. The innovation and importance of this study is to provide a combination of multi-representational scaffolding and gamification mechanisms, and to conduct a multidimensional empirical evaluation to complement the gap in this research field.

2 Literature review

2.1 Limitations of emergency remote mathematics education

In most mathematics courses, students may often learn knowledge, concepts, and skills that are removed from their real-world context (Kelley & Knowles, 2016). As a result, their learning may be less likely to transfer to real-world complex problem solving (Dagoc & Tan, 2018). Some students have negative attitudes toward mathematics, and these negative attitudes affect their performance and motivation, and reduce their learning achievement in mathematics (Liles et al., 2017). In addition, reduced motivation to learn mathematics can lead to students' boredom, lack of curiosity, and difficulty in grasping and understanding complex mathematical concepts during the learning process, all of which can contribute to the negative impact on students' achievement in mathematics (Fouze & Amit, 2017). Ashcraft and Kirk (2001) suggested that students' fears or worries about mathematics cause them to be anxious about learning mathematics, and that mathematics anxiety predicts mathematics test scores (Lukowski et al., 2019), and past research findings suggest that mathematics anxiety leads to poor achievement in mathematics (Foley et al., 2017). The global pandemic of COVID-19 has brought many changes to education. Many schools have had to switch to online remote education. Bao (2020) pointed out that in face-to-face course teaching, teachers often use body language, facial expressions, and speech sounds to deliver lessons, but "body language" cannot be delivered through online courses. Remote education suffers from a lack of feedback from the expressions and behaviors of the students attending the class (Abate et al., 2021), and teachers of remote courses are unable to control what students must learn and therefore rely on student autonomy. Therefore, the implementation of online remote education and its learning effectiveness depend heavily on the high level of active learning and self-organization of students outside the classroom (Bao, 2020; Barlovits et al., 2021). Past research has identified many problems that teachers face during remote education such as lack of information technology equipment in students' homes, lack of communication between students and parents, lack of student motivation, and even effects on students' mental health (Kruszewska et al., 2020). Distance learning requires creating a fun environment in which students can maintain a high level of interest in learning over time (Sansone et al., 2012). A study by Adnan and Anwar (2020) found that most students found remote education to be less effective than traditional learning due to the lack of interaction with the instructor, response time, and lack of traditional course socialization, making it difficult for students to work in small groups in a remote learning mode.

In Huber et al. (2021), it was found that using gamification in emergency distance learning could enhance the interaction of distance learning, and Cantwell et al. (2022) used gamification to design learning activities and found that gamification was a highly acceptable application in emergency distance learning. These two studies are among the very few studies that have examined the use of gamification in emergency distance learning, however, neither study has examined learning achievement, and both suggested that future studies should examine learning achievement.

Therefore, this study aimed to design an online remote gamified teaching activity in order to enhance students' motivation and achieve good learning achievement in the post-pandemic era when remote education may be frequently required.

2.2 Gamified learning

Gamification is intended to use game elements in a non-gaming environment to enhance motivation for participation (Deterding et al., 2011). Gamification began to be emphasized over the past decade and has been used in many different areas, including education (Richter et al., 2015). Among various learning strategies, gamification has been recognized as an effective way to enhance students' motivation, and the addition of game elements in educational systems helps to motivate students and improve their skills and learning achievement (de Sousa Borges et al., 2014). Game elements also evoke a sense of engagement, motivation, and achievement in learners. The most commonly used game elements are points, badges, and leaderboards (Barata et al., 2017; Rodrigues et al., 2019; Saleem et al., 2022).

Huang and Hew (2015) showed that gamified learning was effective in engaging students, and the use of a point system motivated students to complete tasks. Feedback mechanisms play an important role in gamified learning, and immediate feedback on student performance encourages students to become more engaged in learning (Attali & Arieli-Attali, 2015). Past research has shown that gamified learning most affects student motivation, engagement, learning achievement, and social interaction (Kalogiannakis et al., 2021). When students use gamified learning strategies, their learning anxiety and cognitive load are reduced, and it helps to improve their learning performance. Jagušt et al. (2018) found that gamified activities help to improve students' performance in mathematics learning. The use of gamification in mathematics learning can promote the interest of students with low intrinsic learning motivation (Stoyanova et al., 2018).

2.3 Multi-representational scaffolding

The concept of scaffolding is derived from Vygotsky's (1978) theory of cognitive development, the most important of which is his advocacy of the Zone of Proximal Development (ZPD) (Brown et al., 2003). ZPD refers to the gap between the ability of an individual to solve a problem on his or her own and the level of ability achieved with the help of others (Raymond, 2000). The purpose of scaffolding is to provide temporary support while the students are problem solving, but also to help them acquire skills to be able to solve problems independently in the future (Collins et al., 1989; Wood et al., 1976).

Kusmaryono et al. (2020) found that after applying scaffolding strategies in mathematics classrooms, students successfully reflected on and corrected their mistakes when solving previously encountered problems, which further improved their learning achievement and was effective in reducing their mathematical anxiety. Past research has also found a significant decrease in student anxiety with the use of scaffolding strategies (Mitchell et al., 2017) and that scaffolding increases student motivation and learning achievement in a gamified cooperative learning environment (Chen & Law, 2016). In Hou and Keng's (2021) study, a dual scaffolding framework was proposed, which integrates peer scaffolding and cognitive scaffolding for educational games: (1) peer scaffolding, which emphasizes group collaboration in designing game mechanics to facilitate learners' interactive behaviors and discussion behaviors; (2) cognitive scaffolding: in games, players can scan game cards for immediate feedback or additional clues. It was found that the effective use of dual scaffolding helps learners develop higher level cognitive thinking and peer interaction and can facilitate learners' collaborative problem solving.

Liang and She's (2021) study of mathematics instruction found that the use of multiple representational scaffolds promoted students' conceptual understanding and problem-solving abilities in mathematics better than single representational scaffolds. Sutiarso's (2017) study aimed to investigate the effect of various types of scaffolding presentation on students' learning of geometric concepts, and found that diagrammatic or graphic scaffolding was effective for improving students' understanding of geometric concepts, especially for students with learning difficulties. Berthold and Renkl (2009) presented both text and graphs to enhance students' understanding of mathematics. Ott et al. (2018) pointed out that the application of multiple representations not only allows students to learn mathematical problems from multiple perspectives, but also gives students the opportunity to choose their preferred representations and then use other representations as an aid to learning.

2.4 Summary

In summary, many classes have been forced to switch to online remote education or blended learning because of the wave after wave of COVID-19 and its ongoing viral variants. However, as mentioned above, remote education in general poses many limitations for teachers and students. Therefore, in this study, we designed a comparison of the learning achievement and motivation between a remote gamified teaching activity with multiple representational scaffolds and a traditional remote discussion activity, and explored the flow, anxiety, and emotions of the learners in the gamified activity to understand the advantages and limitations of this teaching approach.

2.5 Research hypothesis and research questions

This study used mathematics as the subject matter and the mind tool developed by the research team to design a gamified teaching activity that incorporated multiple representational scaffolds, while using remote synchronous teaching software and Google Jamboard to conduct the activity. The study was divided into a control group and an experimental group. The control group used general distance learning in synchronous distance learning, where the teacher guided the students with learning sheets online, while the experimental group performed the multi-representational scaffolding-based gamified activity designed by this study in synchronous distance learning.

It was assumed that the experimental group would have higher learning achievement and motivation than the control group. In addition to this, we also measured the flow, activity emotions, and activity anxiety of the experimental group. The study assumed that the experimental group would have above median flow, positive activity emotions, and low anxiety. Based on the above research hypotheses, the research questions posed in this study are as follows.

1. What are the differences in the learning achievement of the control group and the experimental group?
2. What are the differences between the control group and the experimental group in terms of motivation?
3. What are the performance of the experimental group in terms of flow, activity anxiety, and activity emotion?

2.6 Online gamified learning activity with multi-representational scaffolds

In this study, we designed a multi-representational scaffold for a synchronized online gamified learning activity, which included several tasks to allow students to learn the unit of "three-dimensional shapes and surface area" in the course, as shown in Fig. 1. During the activity, teachers used the Mind Tool for Gamified Learning (MTGL) (Chen et al., 2022) to plan learning progress and to provide points and scaffolding. Students used MTGL to get learning information and scaffolding, Google Meet to communicate, and Google Jamboard to piece together boards and assemble them to complete the layout.

In Step 1, the teacher introduced the game mechanism and story situation to the students. In this learning activity, the students played the role of an architect, analyzed which geometric shapes make up the three-dimensional shapes of the building, and calculated the surface area to complete the interior painting plan of the building. In Step 2, the teacher showed the task and explained the pictures of the level, including the three-dimensional shape of the building (fixed view), the top view, the bottom view, and the front view. The diagrams were labeled with the length of the base and height (5 min for each question). During the process students could view the scaffolds by paying the accumulation points in MTGL, as shown in Fig. 2, which included various representations of the scaffolds. In Step 3, the students were asked to make an expanded view on Google Jamboard based of the three-view drawing

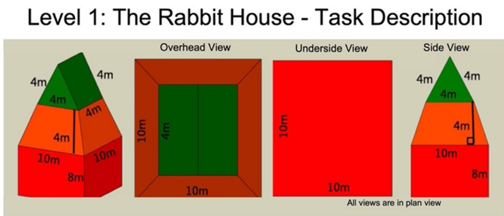
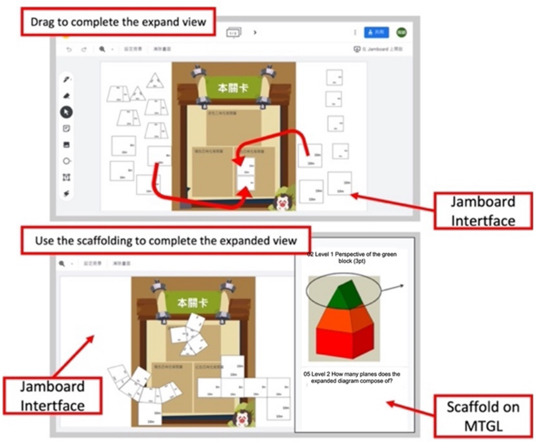
Step	Length of time	Description	The screen on the device
1	5 minutes	Description of the activity mechanism and story situation: you have to act as architects, commissioned by the mayor, need to help the citizens build their desired house, to help the house painted beautiful color!	N/A
2	5 minutes per question (3 questions in total)	The teacher present the questions (three questions in total), which include the name of the building, a static 3D view of the building, a top view, a bottom view, and a front view.	
3	10 minutes per question (3 questions in total)	Group discussion on problem solving. The group has 15 points by default, and after solving each problem, the teacher will give additional points based on performance. These points can be used to purchase the multiple representation scaffolding viewing tips on the MTGL	
4	10 minutes	At the end of the activity, teachers will be awarded based on the ranking of points accumulated	N/A

Fig. 1 The process and mechanism of the gamified activity

seen in Step 2, and to calculate the surface area (10 min per question). After the students finished their answer, they would upload the final result through MTGL for the teacher to check. The teacher reviewed and gave feedback and points immediately after the answers were given. After the answer time was over, the teacher would show the next question. The points earned during the activity could be used by the students to exchange the scaffolds as hints later in the game.

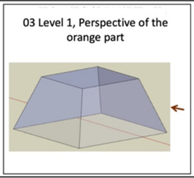
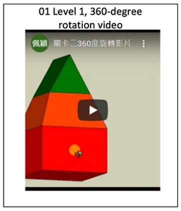
Scaffold	Description	Images
Text Scaffolding	The use of text representations to describe the composition of three-dimensional shapes is the most basic form of representation for learning mathematics, helping students to associate pictorial representations or to make direct connections to visually seen pictorial representations (Rau & Matthews, 2017).	**05 Level 2, How many planes does the expanded diagram compose of?** The green block is composed of 5 planes, the orange block is composed of 6 planes, and the red block is composed of 6 planes
Perspective view	Perspective diagrams that present three-dimensional shapes in static pictures. Graphic representations can provide students with different perspectives on concepts. (Gero & Reffat, 2001)	
360-degree rotation video	Rotating the video 360 degrees to present different viewpoints of the three-dimensional image. 3D graphics' viewpoint transformation can assist students in thinking about how to transform it into an expanded image. (Gero & Reffat, 2001; Haenselmann & Effelsberg, 2012)	
Puzzle on Google Jamboard	Through the operations on the Jamboard, the 3D representations are converted into 2D plane drawings to assist students in calculating the surface area of 3D shapes. In other words, the appropriate mathematical representation conversion in single representation systems or in multiple representation systems is an essential element for developing mathematical thinking and problem-solving skills. (Brenner, et al., 1999; Cramer, Post, & delMas, 2002)	

Fig. 2 Multi-representational scaffolding

3 Methods

3.1 Design and participants

This study adopted a mixed-methods research design using a parallel mixed design (Teddlie & Tashakkori, 2009), in which the quantitative part was the quasi-experimental research method with a pretest-posttest analysis and the qualitative part was an open-ended questionnaire analysis for gamified learning experience. The participants were students from a high school in northern Taiwan aged 15–17 years old. All of the participants had taken a course in *line symmetry and three-view diagrams* concepts prior to high school. They must pass an assessment before entering high school, thus confirming that the participants had a basic prior knowledge of the subject related to this study unit.

Before the study, the participants had experience with distance learning and gamified learning in a physical classroom.

There were 16 participants (6 males, 10 females) in the control group (general remote teaching) and 20 (3 males, 17 females) in the experimental group (teaching by multi-representational scaffolding gamified activity). Purposive sampling was used, with one actual class as a group, to better fit the actual teaching situation. Each group of participants was divided into groups of 4 people for activities. All participants were informed of the details of the experiment and signed an informed consent form before the activity was performed. The research process and scales of this study were reviewed by the Office of Research Ethics, National Chengchi University, Case No. (NCCU-REC-201,812-E091).

3.2 Research procedure

Before the learning activity, the two groups took a pre-test on the learning achievement and motivation scale (25 min), followed by a learning activity (60 min) in which the control group was divided into groups of four to read the problem-solving teaching materials, discuss them online, and complete the learning sheets. The experimental group was divided into groups of four to conduct the abovementioned gamified teaching activities. After completing the learning activities, each group was given a post-test (30 min). Both groups completed the learning achievement and motivation scale post-test. The experimental groups also completed the flow, activity anxiety, activity emotion, and gamified activity feedback questionnaires.

3.3 Instruments

3.3.1 Learning achievement measurement

In this study, the same learning achievement measures were used in the pretest and posttest to evaluate the learning achievement of the learners before and after the teaching activities. The questions were divided into five single-choice questions (1 point each, 5 points in total) and two calculation problems (5 points each, 15 points in total), with a total of 20 points. The test was designed by the researcher, and the expert validity was assessed by a senior mathematics teacher with more than 20 years of teaching experience to determine the correctness of the content and expert validity. Figure 3 shows one of the questions.

3.3.2 Learning motivation scale

According to the ARCS model of motivation proposed by Keller (1987), learning motivation consists of four factors: Attention, Relevance, Confidence, and Satisfaction. This study used a questionnaire adapted from Chen (2008) based on this model, which uses a 5-point Likert scale, with 1 being *strongly disagree* and 5 being *strongly agree*, with higher scores indicating higher learner motivation. In this study, the overall reliability of this scale was 0.975 (Cronbach's $\alpha = 0.975$), which is a high

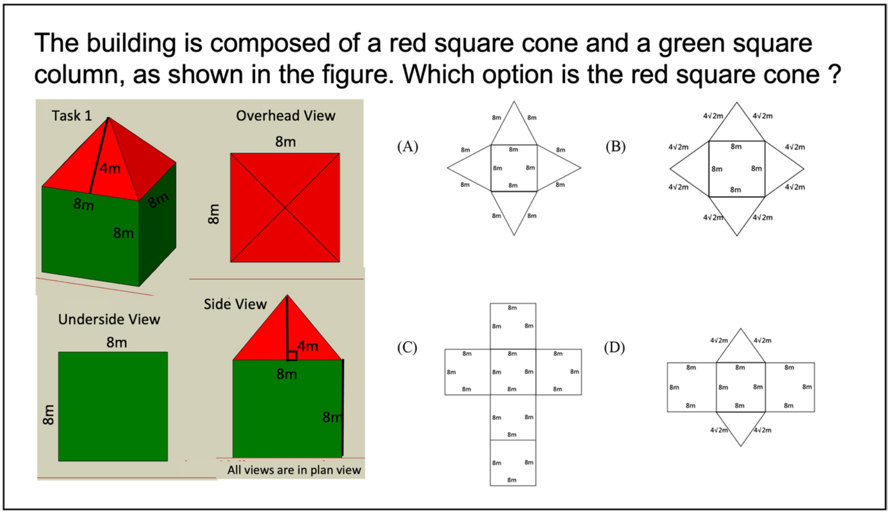


Fig. 3 A question of learning achievement measurement

degree of reliability. Some of the questions are as follows: "The quality of teaching materials helped to hold my attention.", "The way the information is arranged on teaching the materials is helped keep my attention".

3.3.3 Flow scale

To investigate the learners' flow during the learning activities, the flow scale of Kiili (2006) was used as the flow scale, and the Chinese version of the scale was translated and embellished by Hou and Chou (2012). The flow scale is divided into two dimensions: flow antecedents and flow experiences. The questionnaire was designed using a 5-point Likert scale. In this study, the overall reliability of the flow scale was 0.74 (Cronbach's $\alpha = 0.74$), which is acceptable. Some of the questions are as follows: "The goals of the game were clearly defined", "My sense of time altered (either speeded up or slowed down)."

3.3.4 Activity anxiety scale

In this study, to investigate the influence of the activity on the anxiety degree of the learners when they participated in the teaching activities, the Chinese version of Krashen's (1981, 1982) Affective Filter Hypothesis was used, and the activity anxiety scale in the Learning Experience Scale adapted by Hung (2001) was used; its narrative was embellished to better fit this study. A total of eight questions, including a reverse question, were used in this study, with 5 indicating "*strongly agree*" and 1 indicating "*strongly disagree*" on a 5-point Likert scale. The overall reliability of this scale was 0.86 (Cronbach's $\alpha = 0.86$), which is a good level of reliability. Some of the questions are as follows: "The quality of teaching materials helped to hold my attention.", "The way the information is arranged on teaching the materials is helped keep my attention."

3.4 Activity emotion scale

In this study, we referred to the learning emotion scale of Bieleke et al. (2020), which was used to examine the emotions of the learners during the experiment, including positive and negative emotions. In this study, we modified the scale to fit the description of this study. The scale was divided into two dimensions, positive and negative emotions, and a 5-point Likert scale with 12 questions was used. The questions focused on the emotions before, during, and after the learning activity, including enjoyment and hope as positive emotions, and anxiety and boredom as negative emotions. In this study, the reliability of positive emotion was 0.867 (Cronbach's $\alpha = 0.867$) and the reliability of negative emotion was 0.742 (Cronbach's $\alpha = 0.742$). Some of the questions are as follows: "During the game, my learning emotion was happy.", "During the game, my learning emotion was confident."

3.5 Gamified activity feedback questionnaire

The feedback questionnaire for the gamified activity consisted of four open-ended questions as shown in Table 1. The main purpose was to collect students' qualitative feedback on this gamified activity. The questions included asking whether the gamified activity made people want to learn more, whether the scaffolding of the three representations provided in the game contributed to the construction of knowledge concepts, and whether the mechanism of gamification and online manipulation contributed to a deeper understanding of learning.

4 Result and discussion

4.1 Learning achievement analysis

To understand the learning achievement of the two groups of participants under the two teaching methods, the Wilcoxon signed-rank test was used to test the difference between the pretest and posttest of learning achievement as shown in Table 2. The difference between the pre- and post-test scores of students in the control group

Table 1 Gamified activity feedback questionnaire

No.	Question
1	Do you think the three hints (text, perspective, and 360-degree rotation video) used in this activity in the system could help you to learn this course? Which prompt was most helpful to you? Why?
2	Does the way of using Google Jamboard to assemble the boards to the diagram help you understand and solve the spatial concept of the diagram? Why?
3	Does this gamified activity make you want to learn geometry more than a regular math class? Why?

Table 2 Wilcoxon signed-rank test of the learning achievement of the two groups

Group	*N*	*Test*	*M*	*SD*	*Z*	*p*
Control group	16	pre	5.16	2.70	-2.47*	0.01
		post	4.22	2.96		
Experimental group	20	pre	6.38	3.32	-0.75	0.45
		post	6.28	3.93		

*$p < .05$

reached a significant level (Z = -2.47, $p = .01$). The post-test scores were significantly lower than the pre-test scores, indicating that the post-experimental learning achievement of the students in the general distance teaching activity group was significantly lower. Students in the experimental group did not achieve significant differences in learning outcomes after the test (Z = -0.75, $p = .45$), indicating that there were no significant differences in the learning achievements of students in the experimental group before and after the test.

The Mann-Whitney U test was used to compare the learning achievements of the two groups, and the results are shown in Table 3. In the post-test of learning achievement, there was also no significant difference between the two groups (Z = -1.57, $p = .124$), indicating that there was no difference in students' learning achievement after the two teaching activities.

As this study was conducted in the early stage of emergency remote education in Taiwan, students were still not familiar with synchronous remote instruction, as Roman and Plopeanu (2021) showed that students' lack of preparation, technological problems, and negative emotions about the pandemic in the early stage of emergency remote education had a negative impact on their learning performance in remote instruction, resulting in a significant decrease in the learning achievement of students in the control group and no significant increase in the performance of the experimental group after the experiment. There was no difference in the learning performance of the two groups of students. The results of this study also indicate to a certain degree that in the case of emergency remote education, it is more difficult to improve the learning achievement in the short term even if the scaffolding mechanism provides assistance, and without the assistance of a suitable mechanism (e.g., scaffolding or interactive mechanism), it may even lead to a decrease in learning achievement.

Table 3 Mann-Whitney U test of the learning achievements of the two groups

	Group	*N*	Mean Rank	Sum of Ranks	Mann-Whitney U	*Z*	*p*
Pretest	Control group	16	16.22	259.5	123.5	-2.49	0.249
	Experimental group	20	20.33	406.5			
Posttest	Control group	16	15.44	247.0	111.0	-1.57	0.124
	Experimental group	20	20.95	419.0			

4.2 Learning motivation analysis

As shown in Table 4, the results of the Wilcoxon signed-rank test showed that the post-test scores of students' motivation in the control group were significantly lower than the pre-test scores, showing a significant decrease (Z = -3.35, $p = .001$); the post-test scores of students' motivation in the experimental group were significantly higher than the pre-test scores, showing a significant increase (Z = -2.66, $p = .008 < 0.05$).

The pre-test of learning motivation was significantly different for the two groups (Z = -2.36, $p = .018 < .05$) as determined by the Mann-Whitney U test, as shown in Table 5, with the control group having significantly higher motivation before instruction than the experimental group. However, in the post-test of learning motivation, the experimental group had significantly higher motivation than the control group (Z = -3.43, $p = .001 < .01$). The results showed that the experimental group had significantly lower learning motivation before the instructional activity than the control group. In the experimental group, after the gamified learning activity, the learning motivation increased and was significantly higher than that of the control group (as shown in Fig. 4).

The significant decrease in the pre-test (before emergency remote instruction) and post-test (after emergency remote instruction) for the control group could be inferred to be related to the fact that didactic instruction might be less motivating for students (Safapour et al., 2019) and the negative effects of emergency remote education, such as lack of classroom interaction and technology acceptance (Roman & Plopeanu, 2021) may even cause a significant decrease in motivation, which is a challenge when teaching remotely in a pandemic. The significant increase in

Table 4 Wilcoxon signed-rank test for the control and experimental groups' learning motivation

	Pretest		Posttest			
	M	*SD*	*M*	*SD*	*Z*	*p*
Control group ($n = 16$)	3.03	0.29	2.46	0.45	-3.35**	0.001
Experimental group ($n = 20$)	2.69	0.54	3.22	0.67	-2.66**	0.008

$^{*}p < .05$, $^{**}p < .01$

Table 5 Mann-Whitney U Test of the pre-test and post-test of the two groups' learning motivation

	Group	*N*	Mean Rank	Sum of Ranks	Mann-Whitney U	Z	*p*
Pretest	Control group	16	3.03	0.29	86.5	-2.36*	0.018
	Experimental group	20	2.69	0.54			
Posttest	Control group	16	2.46	0.45	52.5	-3.43**	0.001
	Experimental group	20	3.22	0.67			

$^{*}p < .05$, $^{**}p < .01$

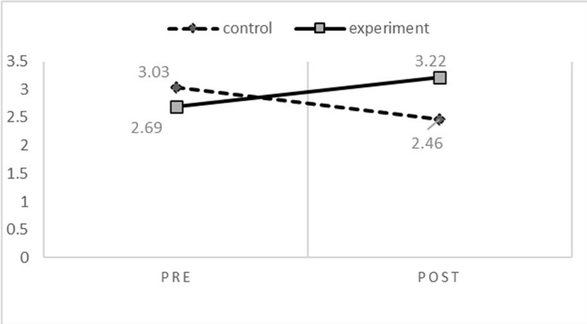


Fig. 4 The mean of the overall motivation of the two groups

motivation in the experimental group might be inferred to be related to the mechanism of gamified learning, such as the interactive, points mechanism in gamified learning that has been shown to increase students' motivation in previous studies (de Borges et al., 2014).

The mechanism of gamified learning, which requires students to solve problems in small groups, may also help to reduce the negative effects of the lack of classroom interaction in emergency remote education to some extent (Roman & Plopeanu, 2021). In the present study, gamified learning was found to be effective for enhancing learning motivation.

4.3 Flow, anxiety, and emotion analysis

In this study, we analyzed the flow, activity anxiety, and activity emotion of the experimental group during the gamified learning activity, as shown in Table 6. The mean flow of the experimental group was 3.52, and the overall flow was significantly higher than the median of 3 ($p = .000 < .001$) using the Wilcoxon signed-rank test.

The mean score for activity anxiety was 2.67, which was significantly lower than the median of 3 ($p = .02 < .05$) as tested with median 3 by the Wilcoxon signed-rank test. Using the Wilcoxon signed-rank test to test the activity emotion against the median 3 showed that the enjoyment dimension was significantly higher than the median before ($p = .019 < .05$) and during the activity ($p = .038 < .05$). The mean score for the boredom dimension was significantly below the median for both the in-activity ($p = .013 < .05$) and the post-activity ($p = .005 < .01$), and the score for both the hope and anxiety dimensions was not significantly different from the median at any stage.

The results of the study revealed that the students' participation in the gamified activity designed in this experiment was high in terms of overall flow, flow antecedents, and flow experience. Since flow is the result of deep concentration in an activity, and in previous studies, students' flow has been considered as a process variable that plays a motivating role in the learning process (Csikszentmihalyi & Seligman, 2000), it is possible to understand the high engagement of learners in this activity, which is like that found in the study of Kalogiannakis et al. (2021).

Table 6 Wilcoxon signed-rank test of flow, activity anxiety, and activity emotion in the experimental group (with median = 3)

Dimensions	*M*	*SD*	*p*
Flow antecedents	3.52	0.69	0.000***
Challenge	3.42	0.81	0.012*
Clear goal	3.78	0.54	0.000***
Feedback	3.56	0.75	0.000***
Control	3.61	0.80	0.001**
Playability	3.22	0.70	0.156
Flow experience	3.52	0.71	0.000***
Concentration	3.52	0.95	0.002**
Time distortion	3.50	0.87	0.003**
Autotelic experience	3.58	0.93	0.000***
Loss of self-consciousness	3.42	0.73	0.017*
Flow All	3.52	0.69	0.000***
Activity Anxiety	2.67	0.77	0.020*
Activity Emotion			
Enjoyment			
enjoy before study	3.50	0.83	0.019*
enjoy in studying	3.45	0.88	0.038*
enjoy after study	3.35	0.93	0.1
Hope			
hope before study	3.20	0.52	0.12
hope in studying	3.00	0.86	1
hope after study	2.85	1.09	0.38

Table 6 (continued)

Dimensions	*M*	*SD*	*p*
Anxiety			
anxiety before study	2.85	1.14	0.565
anxiety in studying	2.75	1.12	0.308
anxiety after study	2.85	1.09	0.527
Boredom			
boredom before study	2.90	1.02	0.642
boredom in studying	2.55	0.69	0.013*
boredom after study	2.45	0.69	0.005**

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

The results indicated that use of gamified mechanisms might reduce students' anxiety during activities, consistent with previous research findings (e.g., Su, 2015). In terms of emotions, it can be found that students enjoyed and did not feel bored during the activity; Grodal (2000) also found that positive emotions were generated when gamers had sufficient game skills and were able to solve the crisis in the game. From the above results, this gamified activity does not create more anxiety for learners in emergency remote education situations, and students have a certain degree of engagement and positive emotions.

4.4 Qualitative feedback analysis of gamified learning activities

In addition to the quantitative assessment, this study also conducted a qualitative feedback survey on the gamified learning activity. The study designed an open-ended questionnaire with three questions to understand the usefulness of various mechanisms for students' play activities, including whether the multi-representational scaffold was helpful in the formation of knowledge concepts, the operation of the representational transformation tool, and whether it was more useful in deepening learning understanding.

4.4.1 Multi-representational scaffolding

Seven (35%) of the students in the experimental group thought that the three types of scaffolding cards provided in the system were helpful for them to learn the unit on three-dimensional graphical spreads. One of them specifically mentioned that the "360-degree rotation video is the most helpful because it can help me see various angles" and one student also mentioned that "hints (i.e., scaffolding) are the most helpful because we can use them to help us learn when we encounter difficult problems that we cannot solve."

4.4.2 Operation of the multi-representational conversion tool

Of the students in the experimental group, 16 (85%) thought that the Jamboard online whiteboard manipulation of the unfolding diagram was helpful for them to understand and solve the spatial concept of the unfolding diagram: (1) In terms of being helpful for learning, three mentioned that "this practical way of manipulation helps me to learn," and one of them said "this way of operation helps me increase my knowledge in this unit" and "after playing this game, I have more knowledge." (2) In terms of promoting thinking, one of them said, "This way of operation can help us to think with our brains." (3) In terms of problem solving, seven students said, "this game design helps to solve the problem," and two said "it is helpful to discuss with the group members to solve the problem." (4) The remaining one student did not think it was helpful for them to learn the module, and thought it was "similar to the effectiveness of the regular class"; the other two students did not provide their opinions.

4.4.3 Gamified mechanism

In the experimental group, 12 students (60%) felt that this gamified activity mechanism would make them want to learn more than a general lecture-based math class; two students (10%) felt that they would not want to learn more; six students (30%) did not express their opinion; and one student was off topic.

According to the questionnaire feedback, it was found that the mind tool was helpful as a scaffold provider, and the multi-representational scaffolds could facilitate students' thinking about spatial concepts in solving problems, and more than half of the students responded that the activity design of this study would make them want to learn mathematics more.

5 Conclusion

The purpose of this study was to investigate the differences in learning achievement, learning motivation of regular distance teaching (control group), and gamified teaching activity with multi-representational scaffolding (experimental group) under emergency remote education. The study also explored the experimental group's flow, anxiety, and emotion performance.

Answer the research question 1, the results of the study indicated that there was no difference in the learning achievement of the two groups. However, it is worth noting that the test scores of the control group decreased significantly, while the experimental group showed no significant difference.

In a study by Stojanović et al. (2021), who conducted a distance learning mathematics course, it was found that the effectiveness of distance learning throughout the course was limited after assessing the participation, engagement, and motivation of distance learning students. It has also been suggested that there is a need to change the content, processes, and methods of teaching mathematics in distance learning (Lavidas et al., 2022), and that the use of a game-based model of distance learning in mathematics may improve student performance (Antonio & Tamban, 2022).

The decrease in performance of the control group may be due to the negative effects of emergency distance education on the quality of learning (Abate et al., 2021; Bower et al., 2015) showed that technology may become a barrier for teachers and students if distance learning is not used properly, and Shi et al. (2021) mentioned that synchronous communication may not be stable, and sometimes could be easily interrupted or stuck, which brings learners a bad learning experience, leading to some content not being accepted in time and so affecting learning efficiency. There was no significant difference in the scores of the experimental group, probably due to the interaction between the advantages of gamified learning and the negative effects of emergency remote learning did not lead to a decrease in students' learning effectiveness.

Feedback from the qualitative questionnaires of the experimental group shows that most students believed that the gamified learning activity could provide them with interaction and discussion and could function as a communication facilitator, which could help to solve the limitation of lack of interpersonal interaction in emergency distance learning (Bozkurt et al., 2020). It has also been found that gamification can help motivate students to actively participate and improve their academic performance in a distance synchronous mathematics teaching environment, and that the reward system in the game improved participant mood, increased teacher-student interaction, reduced anxiety, and alleviated students' feelings of isolation in pandemic (Rincon-Flores & Santos-Guevara, 2021). Also, some students believe that gamified activities with multi-representational scaffolds can facilitate thinking, as students need a higher ability to organize knowledge in emergency distance education (Barlovits et al., 2021), and multi-representational scaffolds provide an opportunity to facilitate students' problem solving and thinking.

Answer research question 2, regarding the learning motivation of the control group, this study found that the negative effects of emergency distance learning may not only cause negative effects on learning effectiveness, but also reduce their motivation. In contrast, there was a significant increase in motivation within the experimental group with gamified learning. Students need to be highly motivated to learn in emergency distance learning (Bao, 2020), and the feedback from the qualitative questionnaire revealed that more than half of the students indicated that gamified activities with multi-representational scaffolds made them want to learn more, which also indicates the potential advantages of using gamified learning in distance learning.

Answer research question 3, as for the experimental group's flow, activity anxiety, and activity emotion performance, it was found that students had a high flow, indicating that they were focused and engaged, and that their anxiety was significantly lower than the median. In terms of activity emotions, it was found that students experienced enjoyment and did not feel bored during the game. Overall, it can be concluded that the gamified learning activities combined with the multi-representational scaffolding is an attractive and immersive design for students. Such results also respond to Huber et al.'s (2021) study that incorporating gamification mechanisms into emergency distance learning can enhance the interaction of distance learning, with the potential to develop facilitation effects comparable to those of physical classes.

In summary, although the proposed online gamified learning and teaching activities with multi-representational scaffolding cannot achieve significant differences in learning achievement from general distance teaching, they can allow students to collaborate and discuss with each other, motivate students to carry out learning tasks, help solve the situation that students cannot focus on the distance classroom, increase students' motivation to learn, reduce learning anxiety, and help them learn with positive emotions. Most of the current research on gamified learning applied to emergency distance learning is only a preliminary exploration of course design. Our study also investigates empirically the multidimensional analysis of learning achievement, flow, motivation, anxiety and emotion. The findings of this study should provide reference for researchers and teachers and may complement the research gap.

5.1 Suggestions and implications

The gamified mechanism brings opportunities for students to interact with each other, and the use of multi-representational scaffolds not only helps students to deepen their impressions, but also helps them to better understand the concepts of mathematics. The integration of the two can enhance students' motivation and increase their cognitive engagement in mathematics learning to achieve flow. Based on the results of the study, the following recommendations are provided:

1. It is recommended that remote learning can be supplemented with gamified mechanisms to stimulate learners' motivation. It is suggested that teachers may consider using mind tools to provide immediate guidance to learners to keep them motivated while teaching at a distance. In terms of mind tool design, it is suggested that the tool can also provide editing functions to allow teachers to design their own remote gamified activities, which can be used in various subject domains and academic systems.
2. It is also suggested that teachers can use scaffolding strategies in gamification activities to provide feedback and guidance to students when they encounter cognitive challenges and to positively influence students' motivation to learn mathematics. Several previous studies have also found positive benefits for learners from the simultaneous use of multiple scaffolds in the gamified learning activities (e.g., Hou & Keng, 2021; Chen et al., 2022). It is suggested that the technology-oriented gamification mechanism can be combined with mobile devices to provide multi-dimensional scaffolding in order to promote motivation and cognitive thinking in distance learning.

5.2 Limitations and future studies

Due to the pandemic situation in Taiwan at the time of this study, and the emergency remote education situation, there were many difficulties and limitations in conducting remote testing in this study, so it was difficult to conduct experiments with larger samples. In addition, the short duration of the experiment might make it difficult to assess the long-term learning outcomes of the students.

Future studies can increase the number of groups and participants, and increase the duration of the experience to improve the overall validity. Future studies could conduct quantitative content analysis and behavioral pattern analysis on the scaffolding cards used by each group, the score records of correct and incorrect answers, and videos of interactive discussions (e.g., Hou, 2015; Hou & Keng, 2021) to gain insight into learners' learning processes and difficulties. This study used geometric units as an example, so there should be limitations to the inferencing if we want to extrapolate to other mathematical units.

Acknowledgements This research was supported by the projects from the Ministry of Science and Technology, Republic of China, under contract number MOST-110-2511-H-011-004 -MY3, MOST-108-2511-H-011 -003 -MY3 and MOST-111-2410-H-011 -004 -MY3.

Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest None

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