Analysis of The Motivational Effect of Gamified Augmented Reality Apps for Learning Geometry

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ABSTRACT

Gamification has been recognised for its motivational power and been increasingly integrated into Augmented Reality (AR)-based educational applications. However, results of the existing studies on the effect of gamified AR apps on learning motivation remain inconclusive. To address this issue, we developed an AR learning app and its three gamified variants - Badges, Points, and Timer. Each of the apps was used by a group of 30 students aged 12-16 years to learn 3D geometry. To assess the impact of these AR apps on learning motivation, we constructed a three-item questionnaire, measuring *Interest*, *Confidence* and *Intention to Use*, which was administered after each of the six rounds of interaction with the apps. Results showed that there were no other significant differences in the motivational effect between the gamified and non-gamified apps, and Points had a stronger learning effect than Badges or Timer. Implications for designing the gamification elements are drawn.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Interaction Paradigms; Mixed / Augmented Reality.

KEYWORDS

Motivation, Geometry, Learning, Gamification, Point, Badge, Time pressure

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1 INTRODUCTION

Augmented Reality (AR) is a form of technology that superimposes a 3D virtual object or content in a real-world environment to create a sense of mixed reality [1]. In the last decade, AR has attracted more and more research efforts in various fields, especially education. A search in the database *Web of Science Core Collection* with the query ("augmented reality" "education use") returned 3,355 results for 2010-2019, which is a nearly fifteen-fold increase as compared with 224 results for 2000-2009. While this is a crude comparison, the surge suggests that researchers and practitioners have progressively recognized the potential of AR as an educational tool. This can be attributed to the ever-increasing sophistication, affordability, and usability of AR technology [2].

Among others, mathematics is one of the educational areas that can benefit from the use of AR, especially geometry. It involves studying different shapes such as pyramid, rectangle and cuboid. A pedagogical challenge is that it is difficult to learn geometric shapes in 2D, especially their cross-sectional representations [3]. AR can help resolve this challenge, because it allows dynamic and interactive 3D manipulations of geometric figures [4]. Learners can move, rotate, reflect or stretch such a figure. With the assumption that AR-based educational tools can be motivational and thus enhance student performance, some research studies (e.g., [5, 6]) were conducted to evaluate the use of AR in learning geometry, but the findings were inconsistent.

For enhancing students' learning motivation, gamification is recognized to be effective, albeit not without controversy [7]. When implemented properly, gamification could improve user engagement. For example, Colpani and Homem [8] proposed a framework for using AR with gamification to assist the learning process of children with cognitive disabilities. Their well-designed framework enabled some positive effect of children's actions, as it required low interaction skills with a usable and child-friendly interface. Bing and Shuxia [9] proposed the gamification concept to promote environmental education through using mobile AR. The key finding of their research was that gamification could help students gain knowledge about the environment and stimulate their interest in environmental subjects. Although the potential of using AR with gamification as an educational tool has been recognised [10], the number of studies that empirically assess the effects of individual gamification elements, such as points and badges, with AR on motivation is still small [11].

Consequently, we aimed to bridge this gap by investigating a specific and key research question: **To what extent do different gamification elements for enhancing an AR-based learning app vary in their motivational effect?** The answer to this question is relevant for informing the design of this emerging educational technology – gamified AR learning apps - which should be usable, useful and desirable. Accordingly, we developed an AR-based app with three different gamification elements: badge, point and timer (challenge). The gamified AR apps enabled students of 12-16 years old to learn geometric shapes in 3D. Their motivational effect was operationalized in terms of students' increased interest as well as confidence in the geometric topics covered by the apps and stronger intention to use the apps (Section 3.2). To address our research question, we conducted an empirical study with altogether

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120 students, who were randomly assigned to one of four conditions: the AR learning app and its three gamified variants (Section 4.1), and their self-reported motivation was repeatedly measured in the course of the experiment.

Overall, the contribution of our work presented in this paper is twofold: First, to provide the lacking empirical evidence for the motivational effect of AR-based learning apps, with and without gamification. Second, to offer a methodological approach to evaluating the motivational effect of gamified AR learning apps.

2 LITERATURE REVIEW

In this section, we first provide an overview of AR in education, followed by a review of the gamification elements on learning and motivation.

2.1 Augmented Reality (AR)

One of the key characteristics of AR is the dual-presence of information with real and virtual displays being overlaid on each other [12]. Wu and colleagues [13] reported that one of the common AR applications is education. Mayer argued with his cognitive theory of multimedia learning [13] that using AR with texts and 2D/3D images can improve learning, because generally people are able to learn from word and picture better than word alone. Accordingly, Sommerauer and Müller [13] examined the use of AR-based technology for education by conducting an experiment at a mathematics exhibition, which was similar to that of Morrison and colleagues [12], where a comparison of the learning effect between the AR-based and non-AR-based exhibits was made. While the results of [12] were inconclusive, [13] showed that museum visitors learned significantly more from AR than from non-AR exhibits. AR has been shown to be effective for enhancing experience in cultural heritage [14].

In evaluating the effect of playing multiplayer mobile AR games on children's communication and motivation, Lissette and Javier [15] showed that the games could elicit positive emotions in children such as enthusiasm, enjoyment and curiosity. Ibáñez and colleagues [16] showed that using AR-based applications was more effective in promoting students' knowledge of electromagnetism as compared with using web applications. Similarly, it was shown that dedicated marker-based AR apps could improve their users' understanding of astronomical phenomena [17]. Another study demonstrated that the inquiry-based AR learning system could significantly improve high school students' knowledge of the gas properties in real-life contexts [18]. In addition, AR-based learning was proved more effective in fostering students' computational thinking in the context of debugging as compared with the traditional approaches [19].

Overall, as stated in the above literature review, in the past decade, the use of AR for education has been extended to a range of domains [20][21]. However, the number of empirical studies focusing on the motivational effect of gamified AR apps on mathematics learning is limited. Hence, it is necessary to collect more empirical evidence to allow solid conclusions to be drawn about the impact of gamified AR educational tools on students' learning motivation.

2.2 Gamification and Motivation

Over the last decade, gamification has been applied as a new approach to learning [22]. The main idea is simple: transforming unexciting, routine activities into engaging and memorable experiences by adding game elements. It can be used to increase learner engagement [23], which comes with a variety of definitions and a core set of keywords such as goal, play, fun, behaviour and motivation [24]. Gamification is defined as "the use of game design elements in non-game contexts" [22]; applying game design patterns and mechanics to improve learners' motivation [25] and thus their productivity by achieving goals with fun and enjoyment.

Indeed, motivation is an essential factor for learning [26]. It can be described as a sense of being "moved to do something" [27]. The two main types of motivation are intrinsic and extrinsic [28]. Intrinsic motivation is the human needs for learning, curiosity, and overcoming challenges such as enjoyment and engagement [29]. On the other hand, extrinsic motivation comes from behavioural results and involves elements that are related to task values such as reward, grade, and punishment [27].

Points and badges are commonly used gamification elements in empirical studies in education [30], [31], [32]. Awarding points based on performance is a way to give feedback and track progress. Players are given points to know how well they are doing as compared to others and how many points they still have to earn to reach their final goal. Kuo and Chuang [33] found that the use of point system in a group decision-making system was found to promote learning by producing a sense of competition in learners. But a well-designed point system was also proved useful in enhancing motivation in non-competitive contexts (e.g. [34]).

Awarding badges is also a form of feedback that will increase student motivation to sustain high performance [35], which consists of signifying components, including visual and textual cues and criteria for determining how a badge can be earned. [32]. While a badge-based reward system proved effective in enhancing intrinsic motivation in students (e.g. [36]), it could have negative impact by decreasing their motivation. For example, the students might find it too difficult to earn badges; the activity made them feel frustrated [37]. The effect could depend upon the badge type as well as user type [38].

There are other game elements such as levels/progression, narrative/story, challenge and time pressure [39]. Time pressure means allowing players to have a restricted period of time to complete a specific task. It can make an activity more enjoyable by giving students timed goals [40]. The use of time pressure (i.e. timer) as a form of challenge can improve motivation by requiring learners to finish a task within a time constraint [41]; it enables learners to work in a more focused manner [42]. However, using time pressure needs to be considered carefully, especially evaluating its effect on learning [43].

3 METHODOLOGY

In this section, we present the methodological framework for empirical studies. We then describe the development of our AR learning app and its variants with different gamification elements as the intervention for enhancing children's learning of 3D geometry.

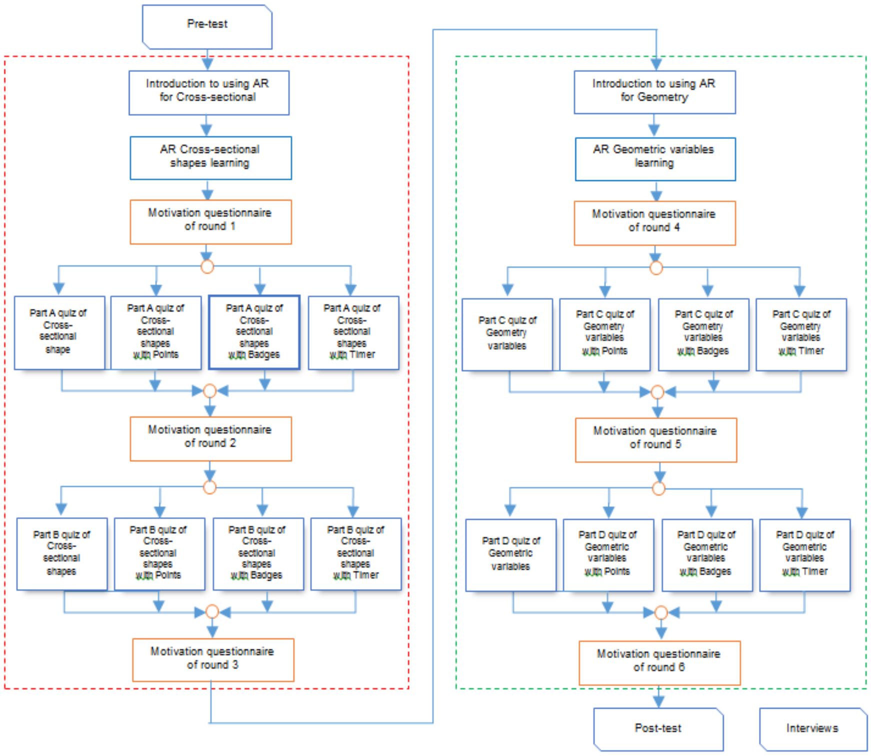


Figure 1: The research methodology

3.1 Methodological Framework

This research aims to analyse how the impact of a gamified AR app for learning 3D geometry on student motivation varies with individual gamification elements it incorporated. The methodological framework is illustrated in Figure 1. The AR gamified app - the intervention - was developed with the Human-centred Design (HcD) approach [44], involving students and teachers as stakeholders of the app throughout the development process. In the empirical study, participants were randomly assigned to four groups under different conditions. Four variants of the AR learning app were: *AR* with *no gamification element (AR-NO), AR with point (AR-PT), AR with badge (AR-BG),* and *AR with timer (AR-TM).* As it was a between-subject experimental design, each participant experienced only one of the four conditions.

3.2 AR Apps Design and Development

In accordance with the HcD approach, the prototype design needed input from teachers and students. Three teachers were interviewed on how what they typically taught geometry in classrooms. After that, the context and learning outcome requirements were specified. It was found that the teachers taught seven key geometric shapes: cone, cube, cuboid, cylinder, prism, pyramid and sphere, and their cross-sectional shapes. They pointed out that it was especially difficult for students to understand cross-sectional shapes which were typically illustrated with cardboards. The feedback from twelve students aged 12-16 years, whom we interviewed about their experience of learning geometric shapes in the traditional classroom setting, resonated with what the teachers had shared. They were taught to draw 3D geometry, depicting 3D shapes in 2D form, in their notebook. Even students who were good at maths argued that they were not confident about their understanding of 3D geometry because of the lack of interaction with 3D shapes. Hence, it was challenging for them to perform 'mental rotation' [45], limiting their study on 3D geometry, especially cross-sectional shapes.

Generally, for the design of a marker-based AR app, Unity 3D based on C# programming was used on Vuforia AR plug-in to build the interactive 3D geometric shapes which were created by using Autodesk Maya. Users can place a 2D image physical marker in front of the camera of a mobile tablet. The marker is captured and processed by the AR system to produce the corresponding virtual 3D object, which is overlaid on the marker to display on the computer screen. Users can view the resulting 3D object from different perspectives by zooming, scrolling, scaling, moving or rotating it. For example, if students want to scale up a geometry 3D object, they just put their two fingers over the tablet screen then slide the two fingers away from each other. Specifically, our AR app prototypes were developed with a set of AR markers consisting of seven shapes with five angles (e.g. 45°, 75°, 90°, 135°, 180°) for learning cross-sectional shapes and geometric variables (Figure 2). The prototypes were iteratively evaluated with the teachers and students to improve their interaction design.

Figure 2: AR markers of seven geometric shapes.

4 EMPIRICAL STUDY

4.1 Procedure

Due to the number of tablets available, four students were randomly chosen from a class to take part in the experimental session after school at one time; there were altogether 40 sessions, amounting to the total of 120 participants A researcher was present throughout each of these sessions to observe student behaviour. The students carried out the planned activities (i.e. the protocol in Table 1) in a classroom at school; a setting with which they were familiar. Each participant interacted individually with the AR app on the tablet with a set of AR markers. They were instructed not to discuss the tasks with their peers during or after the AR app interaction session. Each participant would randomly play one of the four versions: AR-NO, AR-PT, AR-BG or AR-TM. While the AR-NO group received no feedback, the other three gamified groups (Points, Badges, Timer) received feedback during or after they completed in-game quizzes (Table 2).

4.2 Instruments

4.2.1 *Motivation Questionnaire.*

To track the motivational effect attributable to the individual components (i.e. the learning part, four quizzes, feedback) of the intervention, be it the AR app or one of its gamified variants, each participant needed to self-report their motivation at the six checkpoints throughout the session (Figure 1). It is necessary to minimize the fatigue effect [46] and avoid disrupting user experience [47] when the participants had to answer six rounds of the same questionnaire. In reviewing the related work on measuring student learning motivation (e.g. [48], [49], [50]), we identified a recent and widely cited instrument "Science Motivation Questionnaire II" (SMQ II) by Glynn and colleagues [51]. SMQ II consists of 25 items representing five constructs (i.e. intrinsic motivation, self-determination, self-efficacy, career motivation, and grade motivation). Respondents rate each item with a five-point Likert scale. While SMQ II has strong psychometric properties and is adaptable to assess motivation to learn any science subject, we deemed it not suitable for our experiment due to its length, because it would prolong the session and adversely affect the user experience. Nonetheless, the operationalization of its three constructs was relevant: interest for 'intrinsic motivation', confidence for 'self-efficacy' and effort for 'self-determination'. This resonates well with the dictionary definitions of 'motivate': "to make someone want to do something well" or "to stimulate someone's interest in or enthusiasm for doing something." [52] Having analysed the options and constraints, we designed the motivation questionnaire to contain three items:

- Item 1: Using this AR application increases my **interest** in learning 3D geometry.
- Item 2: Using this AR application increases my **confidence** for performing well in 3D geometry.
- Item 3: Using this AR application increases my **intention to continue using** this application.

Each of them is measured by a five-point Likert scale with 1: Strongly Disagree to 5: Strongly Agree. Our basic assumption was that the gamification elements integrated in the AR learning app could have a significant motivational effect on learning geometric shapes in 3D.

4.2.2 *Knowledge tests and in-app quizzes.*

Based on the requirements gathered from the interviews with three math teachers about their experience of teaching geometry (Section 3.2), we constructed the domain-specific knowledge pre-test/post-test as well as quizzes. The pre-test and post-test were actually the same test administered before and after the intervention; the differences between the two test scores were assumed to indicate the learning effect of the gamified AR learning apps. The in-app quizzes, with or without a gamification element, were given during the process of using the app. They were used to measure the immediate learning gain and to sustain participants' attention and interest in the learning activities. The answer format was multiple choice. The tests/quizzes were developed based partly on Van Hiele model [53] including level 0 (Visualization) - the student can recognize a geometric shape as a whole - and level 1 (Analysis) - the student can identify properties of geometric shapes. It consisted of four parts of increasing difficulty (i.e. Part A was the easiest whereas Part D was the most difficult). The tests and quizzes had the same number of questions and structure, but the questions were different (Table 3). For AR-PT, the students were given 10% for each correct answer (no penalty for a wrong answer); the maximum score for Part A/B would be 130% and Part C/D would be 70%. For AR-BG, they were given a badge when they completed all questions in each part. For AR-TM, they were given the time limit of each question. The AR-BG and AR-TM app did not show how many correct answers they had earned during the quiz part or after it was over. Note that no feedback was given for the completion of the pre-test or post-test, which were paper-based, whereas in-app quizzes were digitalised and integrated into the app. There was no time limit to answer the tests or quizzes.

Table 1: The protocol of the experiment with the AR apps.

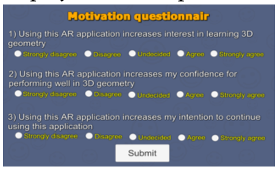
1 **Pre-test:** It has four parts of questions on paper: Part A, Part B, Part C, and Part D

2 

Introduction: Cross-sectional shapes
The introduction is about how to use the app for learning cross-sectional shapes.
Learning cross-sectional shapes

3 

This section is for students to learn cross-sectional shapes. The students need to put a marker on the tablet and then display the 3D shape with the name of its cross-sectional shape. Students can press the cut button to view the cut.

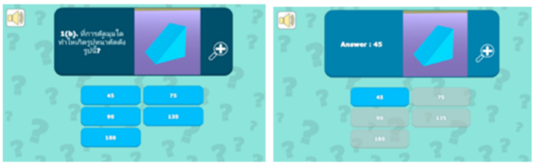
4 

5 **Round 1 of the motivation questionnaire**. Students are asked to complete a three-item questionnaire.
Quiz of Cross-sectional shapes

Quiz of Part A:
The question is about what is the cross-sectional shape after the cut (left). After a student selects an option, the system will show the correct answer with the shape cut (right). Example: The question is about a rectangular shape and the answer is Square

6 **Round 2** of the motivation questionnaire (See step 4)

7 Quiz of Part B:

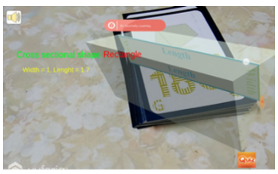


The question is about at which angle is the shape cut (left). After a student selects her choice, the system will show the correct answer with the shape cut at that angle (right). Example: The question is about the cross-sectional shape of a rectangle and the answer is 45.

8 **Round 3** of the motivation questionnaire (See step 4)

9 

10 Introduction: Geometric variables
The introduction is about how to use the app for geometric variables learning.



Learning geometric variables
This section is for students to learn geometric variables. The students need to put a marker on the tablet and then display the 3D shape with its variables such as Length, Width and the name of its cross-sectional shape.

11	**Round 4** of the motivation questionnaire (See step 4)
12	 Quiz of Geometric variables Quiz of Part C: The question is about geometric variables. Example: Which variable represents Radius? (left) After a student selects an option, the system will show the correct answer with the 2D plane and its variables (right).
13	**Round 5** of the motivation questionnaire (See step 4) 
14	Quiz of Part D: The question is on calculation of geometric variable. Example: Find the area of a Circle, where the area is Pi * Radius * Radius (left) After a student selects an option, the system will show the correct answer (right).
15	**Round 6** of the motivation questionnaire (See step 4)
16	The students will take the **post-test** which is the same as the pre-test.

Table 2: The three gamification elements of the AR app

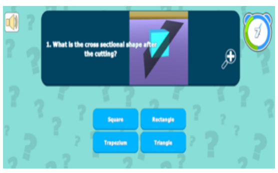
	AR with Points The score of each question is displayed after it is answered; the accumulated score will also be updated (left). When the student finishes all questions in each quiz part, the total score will be shown (right).
	AR with Badges A badge will appear when a student finishes all questions in each quiz part. A badge has three levels, awarding based on the number of correct answers: Gold (Part A/B: 10-13; Part C/D 6-7), Silver (Part A/B: 6-9; Part C/D: 3-5), Bronze (Part A/B: 0-5; Part C/D: 0-2).
	AR with Timer The running time of each question is displayed next to it. When the time limit is over before the student chooses an answer, a beep sound will be emitted indicating the time is over. The correct answer will be presented.

Table 3: The structure of knowledge test and quizzes

Parts	Number of questions	Description: The questions are about . . .
Part A	13	What the cross-sectional shapes are after the cutting. see Table 1. Step 5
Part B	13	At which angle the shapes are cut. see Table 1. Step 7
Part C	7	Geometric variables, see Table 1. Step 12
Part D	7	Formulae with geometric variables. see Table 1. Step 14

4.2.3 Interviews. To gain a better understanding of participants' user experience of the AR apps, semi-structured group interviews were conducted with a group of four students after they had completed the post-test (Figure 1; Section 4.1). The questions addressed their perception of the quality of the app, including its instrumental and experiential quality, and their motivational changes. However, in order to avoid prolonging the session, each group interview was relatively short with the average duration of five minutes. Interviews were digitally recorded.

4.2.4 Hardware. The specifications of the computer tablet where the AR apps ran are as follows: *Screen size*: 8 inches; *Operating System*: Android 7 Nougat; *Size*: 213.3x 7.5 x 123.3mm; *Resolution*: 1920 x 1200; *Memory*: 128 GB.

4.2.5 Participants. A sample of 120 secondary school children aged 12-16 years was recruited. Before using the AR learning app, they were asked to provide their demographic data. The sample was gender balanced (Female = 60, Male = 60). Their knowledge of AR (Mean = 1.52, SD = 1.28, N = 120), knowledge of 3D geometry (Mean = 3.00, SD = 0.55, N = 120) and experience of using tablets (Mean = 2.78, SD = 1.07, N = 120) was generally low (Note: each aspect was measured with a 5-point Likert scale, 1 = very low, 5 = very high).

4.3 Research Hypotheses

Our experimental study employed mixed factorial design with the between-subjects factor (independent variable, IV1) being the AR app with 4 levels (AR-NO, AR-PT, AR-BG, AR-TM) and the within-subjects factor (IV2) being time. The main research goal of our study was to understand the effect of individual gamification elements on learning motivation (Section 4.2.1). Participants were asked to go through the two learning parts – one on geometric shapes and the other on geometric variables – and to respond to four quizzes: Part A, B, C and D (cf. Figure 1; Section 4.2.2). After completing each of the six parts, participants were asked to fill in the motivation questionnaire. We investigated the following research hypotheses (H).

- **H1a**: There are significant differences in the quiz scores of each part across the four variants of the AR app.
- **H1b:** There is a significant positive correlation between the motivation measure and the score for each quiz.
- **H2**: There are significant differences in the motivation level over six rounds of measurement in terms of: **(a)** interest; **(b)** confidence; **(c)** intention to use.
- **H3**: There are significant differences in the changes of the motivation level for each of the gamification element conditions**: (a)** Points; **(b)** Badges; **(c)** Timer.

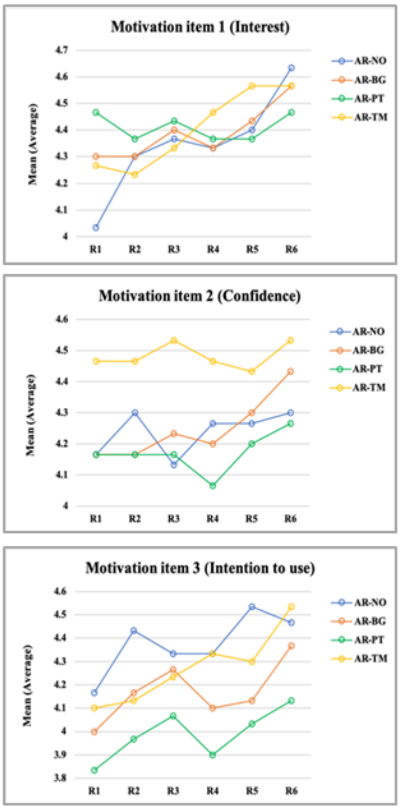


Figure 3: The mean of motivation level: (a) interest (b) confidence (c) intention to use.

5 RESULTS

All 120 participants completed their session. In the following, we present the results of the different measures. However, given the space limit, findings of the interviews are mentioned, where necessary, in Discussion (Section 6).

5.1 Motivation Questionnaire

To test whether we should evaluate the three motivation items separately or average over them as a single construct, we conducted Cronbach's α, a widely used measure of the reliability and internal consistency of questionnaires [54]. As some cases fail to reach the commonly accepted minimum reliability of 0.70, we evaluated the

Table 4: Number of correct answers for the Pre-/Post-test for the four AR-app groups

Part	Statistics	Pre-test scores				Post-test scores			
		AR-NO	AR-BG	AR-PT	AR-TM	AR-NO	AR-BG	AR-PT	AR-TM
Part A (max. 13)	Mean	10.03	9.50	9.27	9.07	10.63	10.27	10.37	9.93
	SD	1.16	1.57	1.55	1.51	1.40	1.57	1.65	0.98
Part B (max. 13)	Mean	8.60	9.47	9.87	9.07	10.63	11.07	11.27	10.73
	SD	2.01	2.67	1.74	2.27	1.71	1.51	1.46	1.93
Part C (max. 7)	Mean	4.97	4.97	5.07	5.30	6.20	5.90	5.87	6.00
	SD	0.89	1.19	0.83	0.95	0.66	0.84	0.68	0.74
Part D (max. 7)	Mean	5.43	5.13	5.60	5.90	6.60	6.20	6.37	6.33
	SD	1.25	0.94	0.81	0.88	0.67	0.85	0.72	0.84
Total	Mean	29.03	29.07	29.80	29.33	34.07	33.43	33.87	33.00
(max. 40)	SD	3.01	3.39	2.64	3.41	3.07	2.90	2.05	3.15

results of the three motivation items separately. Overall, the motivation results, when comparing the first and last round, seem to indicate that all the AR apps led to an increase in Interest, Confidence and Intention to Use. There are some inexplicable fluctuations in the process. Figure 3 portrays the mean rating of each of the three motivation items across the four versions of the AR learning app with each group consisting of 30 participants (section 4.1).

For Interest (Item 1), what stands out from the results is that there were considerable upwards trends in the motivation level of Interest in AR-NO, AR-BG and AR-TM, while the motivation levels of AR-PT group were rather stable over the six rounds. Another interesting point is that AR-NO group had the least Interest level in Round 1, but in the final round (Round 6), their Interest level was higher than the other groups. Intuitively speaking, the four groups should have comparable Interest level in Round 1, given that the learning part of the AR app (i.e. Step 2 and Step 3 in Table 1) was the same across the four groups, and their level of prior knowledge was similar.

For Confidence (Item 2), it can be clearly observed that AR-TM group recorded the highest Confidence level throughout the six rounds. The Confidence level of AR-BG and AR-PT showed a similar pattern, remaining rather stable in the first three rounds, having a dip in Round 4 (after a learning phase) then gradually increased to the highest in the final round. At the same time, the Confidence level of AR-NO group fluctuated between Round 1 and Round 3 and became rather stable between Round 4 and Round 6.

For Intention to Use (Item 3), all four of the AR apps showed an overall trend of increase with some dips. AR-BG and AR-PT group had a similar pattern over the six rounds, their intention level steadily increased from Round 1 to Round 3 and dropped in Round 4 then rose to the highest intention level in the final round. On the other hand, AR-NO showed some fluctuation, despite the initial increase.

5.2 Pre- and Post-tests

To evaluate the impact of the AR learning apps on knowledge gain, the students were asked to complete the pre- and post-tests (Section 4.2.2). The mean and standard deviation of *the number of correct answers* per part of the tests are shown in Table 4. Note that there was no significant difference in the Pre-test performance across the four groups, suggesting that the level of their prior knowledge was comparable. In comparing the changes from Pre-test to Post-test *within* each of the four AR-app groups, there were obvious increases. Results of Wilcoxon tests showed that the differences were statistically highly significant (p <.001). For the sake of brevity, we only report Z for the totals: AR-NO: 4.77; AR-BG: 4.49; AR-PT: 4.53; AR-TM: 4.43. When comparing *across* the four groups pairwise, results of Mann-Whitney U tests showed that there were no significant differences.

Overall, these findings indicated that the students gained knowledge of 3D geometry as a consequence of learning with the AR apps. This encouraging observation, however, contrasted with the discouraging one that the gamification elements seemed playing no role in amplifying the effect of AR.

5.3 Evaluation of Hypotheses

In this section we present results of our evaluation of the hypotheses (Section 4.3). As the empirical data were not normally distributed, as indicated by results of Shapiro-Wilk tests, non-parametric tests were used.

H1a: Mann-Whitney U tests were performed to verify the significance of the differences in the number of correct answers per part (Table 5) between the four AR learning app interventions. Results (Table 6) showed no significant difference in the score of each Part between any of the two AR apps, suggesting that the gamification elements did not enhance the effect of the AR-learning app (cf. AR-NO). Nonetheless, there are two intriguing observations. The scores of the AR-PT and AR-NO groups were comparable (Table 5), higher than those of AR-BG and AR-TM. In comparing the totals (adding up the four parts), the score of the AR-PT group was significantly higher than that of the AR-BG and AR-TM group (i.e. Table 6), implying that Points was a stronger element than Badges and Timer in terms of enhancing student performance. Whether it could be related to the motivational effect was the question evaluated in H1b.

H1b: Results of Spearman's rho tests showed that there were basically no significant correlations between the quiz scores and motivational measures with a few exceptions. The results showed that the AR-NO group had a significant positive correlation between the score for Quiz A and the motivation Item 1 (Interest) of

Table 5: Number of correct answers per part for the four AR apps

Part (max)	Statistics	AR-NO	AR-BG	AR-PT	AR-TM
Part A (13)	Mean (SD)	9.77(2.05)	9.00 (1.66)	9.70 (1.47)	8.93 (8.93)
Part B (13)	Mean (SD)	10.03(1.83)	9.30(2.37)	10.43(1.74)	9.57(1.79)
Part C (7)	Mean (SD)	6.07(0.91)	6.03(0.72)	6.17(0.75)	5.93(1.17)
Part D (7)	Mean (SD)	6.10(0.76)	5.77(0.97)	6.00(0.74)	5.43(1.48)

Table 6: Mann-Whitney test of the quiz scores between of the four AR groups

Quiz	Statistics	AR-NO vs AR-BG	AR-NO vs AR-PT	AR-NO vs AR-TM	AR-BG vs AR-PT	AR-BG vs AR-TM	AR-PT vsAR-TM
Part A	U	322.5	415	328	344	442	350
	Z	-1.921	-0.527	-1.829	-1.606	-0.121	-1.505
	p	0.055	0.598	0.067	0.108	0.904	0.132
Part B	U	377.5	399.5	362.5	330	444	327
	Z	-1.09	-0.76	-1.319	-1.797	-0.09	-1.843
	p	0.276	0.447	0.187	0.072	0.928	0.065
Part C	U	429.5	430.5	435	404.5	442	413.5
	Z	-0.322	-0.307	-0.235	-0.727	-0.128	-0.581
	p	0.747	0.759	0.814	0.467	0.898	0.562
Part D	U	371.5	422	343	397	414.5	366.5
	Z	-1.233	-0.45	-1.675	-0.847	-0.553	-1.331
	p	0.217	0.652	0.094	0.397	0.58	0.183
Total	U	320	424	327	298	445	311.5
	Z	-1.934	-0.387	-1.829	-2.261	-0.074	-2.057
	p	0.053	0.699	0.067	0.024*	0.941	0.04*

Round 2 (r = 0.417, p = 0.022). In contrast, we found in the case of the AR-PT group a significant negative correlation between the score for Quiz C and Interest (r = -0.539, p = 0.002), and Intention to Use (r = -0.505, p = 0.004) of Round 5. This suggests that the higher the score the students earned, the less interest they had in the topic and the lower their tendency to use the app for learning it. This sounds counter-intuitive. One might attribute to the inherent interestingness (or difficulty) of the topic covered in Part C – identification of geometric variables. For the AR-BG and AR-TM groups, there were no significant correlations between the quiz scores and motivational measures at all. The inconsistent patterns across the groups render it hard to explain the observations.

H2: The non-parametric Friedman tests were used for the repeated measures in six rounds. For post-hoc pairwise comparisons, we conducted Wilcoxon signed-rank tests (Table 7).

H2a (Item 1 Interest): The results indicated that all participants (N = 120) had a significantly higher level of interest in Round 3 than Round 2 (Z = -2.236, p = 0.025), as well as in Round 6 than Round 5 (Z = -2.801, p = 0.005). Round 2, Round 3, Round 5, and Round 6 were measured after completing Part A, Part B, Part C, and Part D quiz, respectively. This might be attributed to the fact that the questions of Part A (i.e. what the cross-sectional shape is after the cut) and those of Part B (i.e. at which angle the shape is cut) were closely related; the former could be seen as practice exercises for the latter. As shown in Table 5, for all four AR apps, the students earned more score for Part B than Part A; the increase might contribute to their higher level of interest in learning 3D geometry. Furthermore, Part D covered the topic – computation with geometric variables - with which the students were familiar as compared with Part C that might be perceived as more difficult (cf. Section 4.2.2). For the AR-NO group (N = 30), the participants had a significantly higher level in Round 2 than Round 1 (Z = -1.999, p = 0.046) and Round 6 than Round 5 (Z = -2.121, p = 0.034). It suggested that the students found it was more interesting to learn 3D geometry by answering the quiz (Part A), even without feedback or reward, than by using the markers to learn about the shapes. Nonetheless, for individual gamification elements, no significant differences in Interest between any of the two rounds could be found.

H2b (Item 2 Confidence): All participants had a significantly higher level of confidence in Round 6 than Round 5 (Z = -2.357, p = 0.018). Nevertheless, there are no significant differences in Confidence between any of the two rounds for the participants using AR-NO, as well as for the participants using the AR with the three individual gamification elements (AR-BG, AR-PT, and AR-TM). These observations were consistent with the results for Item 1 Interest.

H2c (Item 3 Intention to Use): All participants (N = 120) had a significantly higher level of Intention to Use in Round 2 than Round 1 (Z = -3.166, p = 0.002); the same was observed for the AR-NO group (Z = -2.530, p = 0.011) and the AR-BG group (N = 30, Z = -2.236, p = 0.025). A significantly higher level of Intention to Use

Table 7: The repeated measures of the motivation across the four AR learning apps

Motivation items Intervention related to each round (R)	Participants	Round 2 vsRound 1 After learning (R1); After Quiz Part A (R2)	Round 3 vs Round 2 R3: After Quiz Part B	Round 4 vs Round 3 R4: After Learning	Round 5 vs Round 4 R5: After Quiz Part C	Round 6 vs Round 5 R6: After Quiz Part D
Item 1 (Interest)	All participants	-	*	-	-	**
	AR-NO	*	-	-	-	*
Item 2 (Confidence)	All participants	-	-	-	-	*
Item 3 (Intention to use)	All participants	**	-	-	-	*
	AR-NO	*	-	-	-	-
	AR-BG	*	-	-	-	*
	AR-TM	-	-	-	-	*

Note: * $p < .05$, ** $p < .01$; only those with significant differences in at least one of the comparisons are in the table

Table 8: Pairwise comparisons between the AR apps with significant differences

Intervention	Item 1 (Interest)					Item 2 (Confidence)					Item 3 (Intention to use)				
	R2-R1	R3-R2	R4-R3	R5-R4	R6-R5	R2-R1	R3-R2	R4-R3	R5-R4	R6-R5	R2-R1	R3-R2	R4-R3	R5-R4	R6-R5
AR-NO vs AR-BG	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-
AR-NO vs AR-PT	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-
AR-NO vs AR-TM	*	-	-	-	*	-	-	-	-	-	*	-	-	-	-

Note: * $p < .05$

in Round 6 than Round 5 were found in all participants (N = 120, $Z = -2.465$, $p = 0.014$), the AR-BG group (N = 30, $Z = -2.070$, $p = 0.038$) and the AR-TM group (N = 30, Z = -2.070, $p = 0.038$). These observations were consistent with the results for Item 1 Interest and Item 2 Confidence.

H3: Results (Table 8) show the significant differences in AR-NO vs AR-BG on the difference in Confidence (Item 2) in Round 3 and Round 2 (U = 392.0, $p = 0.047$). For AR-NO vs AR-PT, the two groups had a significant difference in Interest (Item 1) in Round 2 and Round 1 (U = 329.0, $p = 0.018$). For AR-NO vs AR-TM, the two groups had a significant difference in Interest in Round 2 and Round 1 (U = 351.0, $p = 0.042$), Round 6 and Round 5 (U = 375.0, $p = 0.021$) and Intention to Use (Item 3) in Round 2 and Round 1 (U = 362.5, $p = 0.046$). Overall, these results suggested that using these gamification elements as a means to amplify the effect of the AR intervention seemed *not* working; they did not have any significant impact on the motivation level of the participants who tended to perceive the gamified AR apps relatively the same.

5.4 Perceived effect of the AR app

As the last step of the experimental session, the group of four students was interviewed for about five minutes, due to the time constraint. They were asked to share their perceived quality of the AR apps and improvement suggestions. The apps were generally positively received. Some student indicated that they were more able to learn geometry with the AR app than a classroom-based approach because the shapes were displayed in 3D rather than in 2D. Specifically, with the AR apps, the students could zoom, scroll, resize and view the 3D geometric shapes from different angles, enabling them to develop a better understanding of the shapes. Furthermore, all students would recommend the AR apps to others because they had fun, especially with the quizzes. Nonetheless, some students suggested that the apps should support a wider range of cutting angles instead of only five. Some students also stated that they could not answer some questions due to the time limit, although they knew the correct answers; the use of the timer caused frustration rather than fun then.

6 DISCUSSION

The empirical data of our study indicated some intriguing observations about the use of three different gamification elements – Points, Badges and Timer - for enhancing the potential of AR-based learning apps. Our specific focus was to study whether these elements had varying motivational effects, which might influence student learning performance.

6.1 Revisiting the Hypothesis

H1a: While there were no significant differences in the scores for individual parts of the quiz across the four AR apps, the total of the quiz parts suggested that Points seemed more effective than Badges and Timer. This finding is consistent with the existing research studies, which showed that Points was suitable for motivating learning activities (cf. [33]) whereas Badges and Timer could negatively affect student learning (cf. [37], [43]).

H1b: When the AR-NO group finished the Quiz Part A – with the least difficult questions, they were positively interested in the app. In contrast, the AR-PT group were negatively interested and didn't intend to use in the app when they completed the Quiz Part C – with the difficult questions. One possible explanation for this result is that using AR-PT might decrease the level of Interest and Intention to Use when the students were learning complex 3D geometry. This observation is *not* consistent with the theoretical consideration about the potential of Points for increasing student motivation in dealing with challenging topics (cf. [34]).

H2: The findings summarised in Table 7 indicated that *all participants* (N = 120) had a significant increase in the level of Interest, Confidence and Intention to Use after answering Part D (Round 6) as compared with answering Part C (Round 5). It suggested that there might be a dip in Round 5 leading to the contrast. However, in inspecting Figure 3, several dips were observed in Round 4 (the learning part) rather than Round 5. This might imply that something inherent in Round 6 contributed to the significant jump. We speculated two reasons: First, the students' familiarity with the topic of Part D (i.e. feedback from the interview) made them feel encouraged to explore it further with the app; Second, their awareness that Part D was the last activity with the app prompted them to give positive final evaluation (i.e. social desirability bias [55]). For Intention to Use, it was interesting to see that there were significant changes between Round 1 and Round 2, suggesting that the students were motivated to use the given app when they tried it out. However, the novelty effect seemed waning in the coming rounds.

H3: The findings of using AR-TM, AR-PT, and AR-BG demonstrated that there were differences in the changes of the motivation level between the AR apps with and without gamification elements. The findings of using AR-TM we obtained were in line with the research on applying Timer as a game challenge (cf. [41]). This showed that Timer could increase student motivation as compared with AR-NO in terms of Interest and Intention to Use. However, it could be frustrating for some students who did not respond fast enough, as shared in the group interviews (Section 5.4).

6.2 Implications for Redesign of the Gamification Elements

Based on our empirical findings, we draw implications for designing AR learning apps with the three gamification elements investigated. Our results indicate that using Points and Timer could not improve student confidence in the learning topic. This might be attributed to the potential drawback of presenting *continuous feedback* [56] ; students might feel intimidated or pressured by the points they failed to gain because they chose a wrong answer or their response time exceeded the limit. Instead of serving as encouragement or positive feedback, the ongoing display of the cumulative score and a clicking stopwatch with the time left could be perceived as punishment and coercion to perform (NB: feedback from the interview). Hence, we propose using *delayed feedback* [57] to show accomplishment only when a student completes one part of the quiz. For Points, it will be the final accumulated score whereas for Timer, the shortest response time for a correct answer. This could mitigate the perceived performance pressure. Badges also relies on the same delayed feedback mechanism, but the nature of feedback (score vs. time vs. icon) is different.

Badges seemed effective in increasing the students' Intention to Use the AR apps after they attempted the initial task. However, the positive effect did not persist throughout the process, especially when the novelty effect vanished. Our three-level-badge system (Table 2) may be not discriminating enough. For instance, getting 10 to 13 correct answers (out of 13) can earn a Gold badge, but getting all questions correct should be given a higher recognition. Hence, we propose a broader range of badges which corresponds to a finer grade of performance. Moreover, badges should also be linked to the task difficulty level and to the student effort. For the former, accomplishment in a more complex task should be recognized with a more finely crafted badge to sustain the students' motivation to earn the hard-to-get badge (cf. collectibles of different values). For the latter, when failing in the first attempt students can be given different options that demand their increasing level of effort: getting the correct answer; taking a second attempt of the same question; attempting another similar question. Badges awarded can be based on the combination of these aspects. This is to ensure that all badges they have earned are meaningful and relevant.

In addition, to provide students with a stronger sense of control, which may in turn enhance their motivation, they can be given the opportunity to choose the type of gamification element they prefer for subsequent learning activities after they have experienced all of them as the tried-and-tested approach.

6.3 Limitations

Our study has limitations which organizationally and technically we could not address within the constraints of our research project. First, we compared the four different AR apps, with and without gamification. However, there was a lack of a control group who did not use AR to learn 3D geometry. For our future work, we plan to compare an AR-based gamified approach with their conventional non-AR counterpart. Second, the method we primarily used was questionnaire, leading to mostly quantitative data. While we supplemented such data with the post-session interviews, which were group-based and rather short because of the concern of prolonging the session. Results from the motivation questionnaire enabled us to understand the student motivation level of using the four AR apps. However, more in-depth understanding of their motivation could be gained if we were able to take video-recordings while they were interacting with the apps, thereby observing their verbal (think aloud) and non-verbal behaviours such as facial expressions to derive their motivational changes. Third, our sample size was reasonable for the statistical analysis methods applied, but could have been larger to further substantiate our findings. The process of data collection was time-consuming, which was limited by the number of mobile tablets available. To ensure that user experience would not be undermined by the quality of the hardware used, including high screen resolution and fast speed, the tablets used were not cheap (Section 4.2.4). The limited budget of the project did not allow us to purchase more than four. For our future work, we will look into the trade-off between the costs for quality hardware and user experience to optimise the threshold for cost-effectiveness.

This issue will have wider implications for the uptake of AR-based educational tools in schools.

7 CONCLUSION

The AR-based gamification approach is playing an increasingly important role in education, given the proven ability of both AR and gamification to enhance student motivation. In this study, we attempted to investigate whether the four different AR-based learning apps would have varying impacts on student motivation, which we operationalized as three constructs - Interest, Confidence, and Intention to Use. It was encouraging to observe that the participating students demonstrated a significant knowledge gain as a consequence of interacting with the respective app, regardless whether and which gamification element (Points, Badges or Timer) was integrated in the app. On the other hand, it was rather astonishing that no significant differences between the gamified and non-gamified version of the app in terms of their motivational effect were found.

With regard to the in-app quiz scores, learning with the AR with Points (AR-PT) was more effective than that with Badges (AR-BG) or Timer (AR-TM). Therefore, the use of Points could enhance student motivation. In contrast, it might decrease the level of Interest and Intention to Use of the students for learning complex concepts. Another intriguing observation of our study was that the students' intention to continue using the AR app would fade over time. To sustain the use of the AR app, which proved beneficial for fostering their learning, the design of the three gamification elements needs to be improved. Our results implied that continuous feedback mechanism was inefficacious, because of extra performance pressure perceived by the students. In its place, the delayed feedback approach seems more promising.

Regardless of the limitations described above, our study has made some valuable contributions to this burgeoning research area by providing empirical evidence and methodological approaches, which will be useful for future research and the development of educational AR gamification apps. Nonetheless, designers of gamified AR-based learning apps ought to ensure that their designs can maximize the potential of this promising educational technology while being aware of its possible negative impact such as frustration.

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