

When integration backfires: exploring collaborative gamification in mathematics classroom

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ABSTRACT

As the importance of mathematics literacy increased sharply in the era of artificial intelligence (AI), the present study developed a new teaching modality—collaborative gamification—to reduce mathematics anxiety and increase mathematics intrinsic motivation. A quasi-experimental, between-subject design using pre-existing classroom groups was employed to explore the effects of different teaching modalities on mathematics anxiety, mathematics intrinsic motivation, and mathematics achievement, and to examine whether the achievement outcomes could be mediated by these psychological factors. A total of 175 Malaysia Form 1 students were separated and exposed to different mathematics teaching modalities for one week. Results supported the effects of collaborative learning and gamification on psychological factors, which contributed to higher mathematics achievement. However, collaborative gamification neither reduced mathematics anxiety nor increased mathematics intrinsic motivation and was instead associated with lower mathematics achievement. These counterintuitive findings may be explained by the increased instructional complexity that result in cognitive overload, limiting students' capacity for conceptual processing. The counterbalancing effect of elements may explain the non-significant improvement in psychological factors. These findings highlight the importance of careful instructional design, emphasizing the need to limit extraneous elements, align pedagogical features with learning objectives, and preserve sufficient time for concept development when implementing student-centered teaching modalities.

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1. INTRODUCTION

The rise of artificial intelligence (AI) has undoubtedly increased the importance of mathematics literacy [1]. However, Malaysia secondary school students continue to underperform in various international mathematics assessment such as Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS) [2], [3]. Such results indicated the need to examine the underlying factors, especially when no significant improvement was observed despite the cognitive demands and academic rigor of mathematics syllabus were increased to meet global benchmarks [4], [5].

Among various factors, mathematics anxiety and mathematics intrinsic motivation are two of the most discussed factors when it comes to explaining mathematics achievement. Defined as the feeling of tension and fear towards mathematics activity [6], students with high mathematics anxiety are suggested to avoid mathematics tasks and have lower mathematics achievement, which further worsen their mathematics

anxiety [7]–[10]. On the other hand, students with low mathematics intrinsic motivation are suggested to have low desire or drive to engage in learning mathematics for the sake of learning [11]. These students generally have less willingness to engage or participate in solving mathematics tasks, therefore had lower mathematics achievement [12], [13].

Unfortunately, several studies had suggested Malaysia secondary school students are facing high mathematics anxiety or low mathematics intrinsic motivation [14]–[17], which may explain the low achievement in the mentioned international assessment. The root cause of such phenomenon is suggested to be traditional teaching method, a teaching method where teacher acts as the center of teaching, while students being passive listeners [18]. Such teaching modality is reported to be the mainstream mathematics teaching modality in Malaysia due to its efficiency to deliver knowledge in short period of time [19], [20]. However, the authoritarian teaching style associated with it may create fearsome classroom environment that increase students' mathematics anxiety, while the difficulty in understanding and remembering the concepts in short period of time may lower their mathematics intrinsic motivation [21]–[24]. The prevalence of mathematics anxiety and low mathematics intrinsic motivation were also suggested to be particularly pronounced during the transition from primary school to secondary school, as students adapt to increased instructional demands and shifts in their self-belief on mathematics competence [25].

Student-centered teaching modalities on the other hand are suggested to have overcome the issues. For example, collaborative learning where a group of people work together to achieve a common goal [26], has long been suggested to reduce students' mathematics anxiety due to its social interaction characteristics. Students get to learn mathematics in a supportive and collaborative environment, while opportunities are given for students to trial and error in a non-competitive classroom, therefore reducing their mathematics anxiety [27]–[29]. In addition, as mathematics is often perceived as a boring subject, the implementation of gamification, inclusion of game element in non-game setting [30], is suggested to have boosted students' mathematics intrinsic motivation. Due to the fun elements in gamification, students exposed to such teaching modality reported sustained interest in learning mathematics and obtain higher achievement throughout the mathematics learning process [31]–[35].

However, both teaching modalities are suggested to suffer from different limitations. For example, the diffusion of responsibility often contributed to the ineffectiveness of collaborative learning and may even hinder the mathematics intrinsic motivation [36]–[38]. Furthermore, the nature of competition in gamification and the anxiety aroused from the failure to achieve top position may worsen students' mathematics anxiety and mathematics intrinsic motivation [39]–[42].

Interestingly, while both teaching modalities are set back by their limitations, integrating them into new teaching modality, namely collaborative gamification, may serve as a solution. In this teaching modality, gamification and collaborative learning function in a complementary manner to enhance students' learning experiences. Gamification may serve to increase students' motivation to participate in collaborative learning, while collaboration may provide a supportive social context that reduce the potential mathematics anxiety associated with competitive game elements [43], [44]. Specifically, group-based competition in collaborative gamification may satisfy students' need for relatedness and competency, thereby reducing mathematics anxiety that may arise from individual competition in traditional gamification. Moreover, as collaborative gamification allow failure to be accepted, it may alleviates students' fear of negative evaluation when engaging in mathematics tasks [45], [46].

In short, reliance on traditional teaching methods may bring adverse effects to students' mathematics learning. Although student-centered modalities such as collaborative learning and gamification may improve mathematics anxiety and intrinsic motivation, their effectiveness may be constrained by several barriers when implemented separately. In addition, existing studies have predominantly examined gamification and collaborative learning as separate instructional approaches, leaving limited empirical evidence on the effects of integrating these modalities. Consequently, little is known about their combined effects on students' mathematics learning, particularly in comparison with traditional and single-modality teaching approaches.

Therefore, by comparing collaborative gamification with three existing teaching modalities, present study aimed to explore the effects of different teaching modalities on mathematics anxiety, mathematics intrinsic motivation, and mathematics achievement among Form 1 students, and to examine if the effects on mathematics achievement can be attributed to mathematics anxiety and mathematics intrinsic motivation. It is hypothesized that:

- Students exposed to collaborative gamification will report significantly lower mathematics anxiety compared to students exposed to collaborative learning and traditional teaching method.
- Students exposed to collaborative gamification will report significantly higher mathematics intrinsic motivation compared to students exposed to gamification and traditional teaching method.

- Students exposed to collaborative gamification will report significantly higher mathematics achievement compared to students exposed to other teaching modalities.
- Mathematics anxiety will partially mediate the effect of teaching modalities on mathematics achievement, such that teaching modalities will reduce mathematics anxiety, which in turn increases mathematics achievement.
- Mathematics intrinsic motivation will partially mediate the effect of teaching modalities on mathematics achievement, such that teaching modalities will increase mathematics intrinsic motivation, which in turn increases mathematics achievement.

The present study may contribute to the literature on instructional design by offering insights into how collaborative learning and gamification can be integrated to improve students' mathematics learning. The integration of teaching modalities may encourage educational practitioners to move beyond relying on traditional teaching methods to explore alternative teaching modalities that respond more effectively to diverse learner needs. In addition, the potential of creating an engaging, supportive and interactive learning environment may highlight and raise the awareness of implementing teaching modalities that not only promote achievement but also attend to students' emotional and motivational needs. Furthermore, if it demonstrates great potential to address challenges in mathematics learning, collaborative gamification can be implemented in mathematics teaching to support students who experience high anxiety or lack of intrinsic motivation in mathematics learning.

2. METHOD

2.1. Research design

The present study adopted a quasi-experimental, between-subjects design using pre-existing classroom groups assigned to one of four teaching modalities: traditional teaching method, collaborative learning, gamification, or collaborative gamification. Three dependent variables were examined: mathematics anxiety, mathematics intrinsic motivation, and mathematics achievement. Mathematics anxiety and mathematics intrinsic motivation were assessed both before and after the intervention while mathematics achievement was measured only after the intervention. Random assignment was not feasible due to the use of intact classrooms; however, baseline performance across groups was comparable.

To ensure the validity and reliability of the study, instructional materials, lesson duration, and learning objectives were standardized across all groups. In addition, all teachers followed the same teaching guide to minimize instructional bias. Pre-test and post-test measures further helped control individual differences, supporting internal validity.

2.2. Participants

A total of 175 students (male and female) from Kuen Cheng High School were recruited for present study [47], [48]. Convenience and purposive sampling were adopted, whereby only Form 1 students aged between 12 and 14 years who were currently enrolled in a mathematics course were recruited, as this group of students has been suggested to be more vulnerable to mathematics anxiety and low mathematics intrinsic motivation due to the transition from primary to secondary school. Approval was obtained from the school prior to data collection, and participation was entirely voluntary. No compensation was provided for participation. There was no personal or professional relationship between the researcher and the participants and therefore no conflict of interest was present.

2.3. Research materials

2.3.1. Teaching modalities

Traditional teaching method in present study was a teacher-centered teaching method where students act as passive recipients of knowledge and was the mainstream mathematics teaching modality in the approached school [18]. Collaborative learning is a situation where groups of students work together to solve, complete or create something [26]. In present study, think, pair, share (TPS) model was adopted when designing collaborative learning [49], [50]. Gamification is defined as the use of game elements in a non-game system [30]. In present study, the Pyramidal design model of gamification was adopted when designing gamification [51], [52]. Collaborative gamification in present study is treated as a situation in which students work together to learn something in a gamified learning environment. Both TPS model and Pyramidal design model of gamification were adopted when designing collaborative gamification.

2.3.2. Demographic form

Demographic questionnaire was prepared for participants to fill out their age, gender, races, and a special code solely used to identify participant's pre and post questionnaires paper.

2.3.3. Math anxiety scale

The math anxiety scale (MAS) from Mahmood and Khatoon [53] was adopted in present study to measure participants' mathematics anxiety. The MAS had excellent inter-item reliability (Cronbach's $\alpha=0.87$) in measuring mathematics anxiety among secondary school students. The MAS consists of 14 items scored on a 5-point Likert scale ranging from 1 "strongly disagree" to 5 "strongly agree". Total score on the scale was used, where scores between 14-32 indicating low mathematics anxiety; 33-51 being moderate mathematics anxiety; 52-70 being high mathematics anxiety [54]. As present study recruited Chinese secondary school, the English version of MAS was back translated and reviewed into mandarin by five bilingual individuals with adequate knowledge in questionnaires development. The translated scale demonstrated good internal consistency (Cronbach's $\alpha=0.95$).

2.3.4. Intrinsically motivated math learning subscale of math motivation questionnaire

The intrinsically motivated math learning subscale of math motivation questionnaire (MMQ) from Fiorella *et al.* [55] was adopted to measure participants' mathematics intrinsic motivation. The scale consists of three items scored on a 5-point Likert scale ranging from 1 "never" to 5 "always". The scale had excellent inter-item reliability (Cronbach's $\alpha=0.851$) in measuring mathematics intrinsic motivation among Malaysia secondary school students [55], [56]. Total score on the scale was used, where scores lower than 1 standard deviation (SD) below the mean are counted as low mathematics intrinsic motivation while scores higher than 1 SD above the mean are counted as high mathematics intrinsic motivation. Similar to the MAS, the scale was also back translated and reviewed into Mandarin by five bilingual individuals with adequate knowledge in questionnaires development. The translated scale demonstrated good internal consistency (Cronbach's $\alpha=0.91$).

2.3.5. Mathematics achievement test

The mathematics achievement test (MAT) was a mathematics test paper developed by mathematics teachers and reviewed by the head of department in the school approached. To measure participants' mathematics achievement. The MAT consists of 4 multiple choice questions (1 mark each) and 6 written questions (2 marks each). The test items were aligned with first three levels of Bloom's taxonomy (1 mark for remembering, 8 marks for understanding, and 6 marks for applying). Total scores ranging from 0 to 15, where a higher score indicates a higher mathematics achievement.

2.4. Procedures

Upon receiving approval from the school, a 3-hour training course on teaching modalities was conducted to brief and train mathematics teachers on the teaching modalities used in present study. The training course covered an introduction to different teaching modalities and their potential effects on students' mathematics learning, the underlying theory of each student-centered teaching modality, and the procedures for designing and implementing them. Four teachers were selected to design a 1-week lesson plan using one of the teaching modalities, which were then reviewed and discussed by the researcher to ensure the same topic and identical practice questions were used. At the same time, four classes of Form 1 students were given parental and child assent forms which outlined the details of the research and information on confidentiality.

A total 175 participants were asked to fill out a demographic form, the MAS, and the intrinsic motivation math learning subscale from the MMQ. Participants were then exposed to one of four teaching methods for one week in learning counting system. At the end of the workshop, students completed the same set of questionnaires again and the MAT and were thanked for their participation. The entire study took approximately 5 hours to complete.

3. RESULTS AND DISCUSSION

Present study explored the effects of different teaching modalities on mathematics anxiety, mathematics intrinsic motivation and mathematics achievement. It also examined whether the effects on mathematics achievement can be attributed to mathematics anxiety or mathematics intrinsic motivation.

3.1. Descriptive statistics

Table 1 shows the descriptive statistics of demographic variables. Males constituted 46.9% of the participants while female constituted 53.1%. The participants were all Chinese and were 13 years old predominantly. Table 2 shows the prevalence of mathematics anxiety and mathematics intrinsic motivation at the beginning of the study, before the teaching modalities were implemented. The mean score of pre-mathematics anxiety level fell at moderate level ($M=40.83$, $SE=0.999$). However, 25% of participants ($N=44$) reported high mathematics anxiety and only 27% of participants ($N=47$) reported low mathematics

anxiety. On the other hand, the mean score of pre mathematics intrinsic motivation was at moderate level ($M=9.30$, $SE=0.25$). 25% of participants ($N=44$) reported low mathematics intrinsic motivation while 17% of participants ($N=30$) reported high mathematics intrinsic motivation.

Table 1. Sociodemographic characteristics of the study sample ($n=175$)

Characteristics		N (%)
Gender	Male	82 (47)
	Female	93 (53)
Age	13	174 (99)
	14	1 (1)
Race	Chinese	175 (100)
	Other	0 (0)

Table 2. Prevalence of mathematics anxiety and mathematics intrinsic motivation

Variables	Mean	SE	Categories	N (%)
Mathematics anxiety	40.83	0.999	Low	47 (27)
			Moderate	84 (48)
			High	44 (25)
Mathematics intrinsic motivation	9.30	0.25	Low	44 (25)
			Moderate	101 (58)
			High	30 (17)

3.2. Effects of teaching modalities on mathematics learning

Two one-way independent analysis of covariance (ANCOVA) were run separately to test the effect of teaching modalities on mathematics anxiety and mathematics intrinsic motivation, after controlling for the pre-test score. As all participants did not have pre-knowledge on the mathematics topic taught in present study, a one-way independent ANOVA was run to test the effect of teaching modalities on mathematics achievement. All the assumptions tests were met, and the results suggested teaching modalities to have significant effects ($p \leq 0.001$) on all three dependent variables, as shown in Table 3. Post-hoc analyses were run to further examine whether the difference of participants' mean scores between different teaching modalities were significant. Figure 1 shows the summary of the post-hoc analysis results.

Table 3. Effects of teaching modalities on mathematics anxiety, mathematics intrinsic motivation, and mathematics achievement

Dependent variables	df1	df2	F	<i>p</i>	Partial η^2
Mathematics anxiety	3	170	5.46	0.001	0.10
Mathematics intrinsic motivation	3	170	7.36	0.001	0.31
Mathematics achievement	3	171	64.90	<0.001	0.53

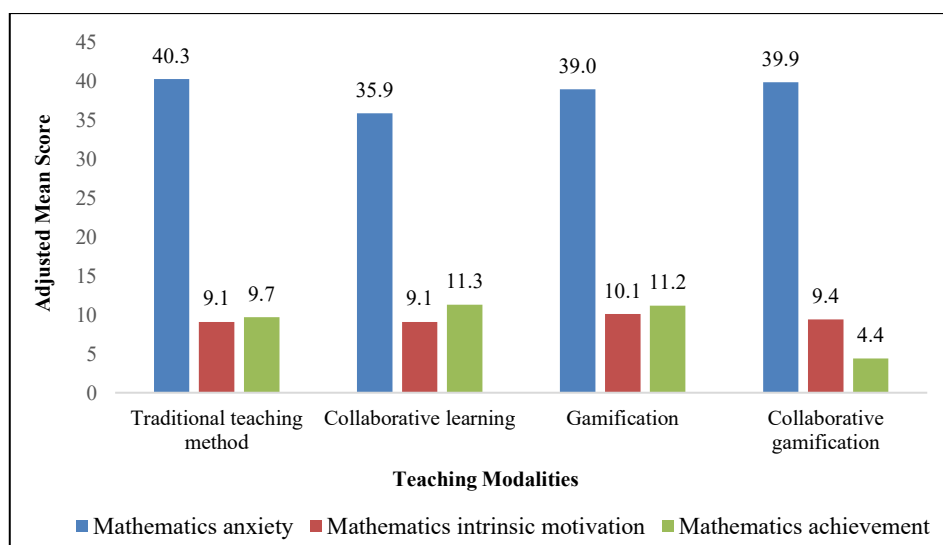


Figure 1. Participants' mean scores between different teaching modalities

3.2.1. Mathematics anxiety

Post-hoc analysis shown in Table 4 revealed that participants exposed to collaborative learning had significantly lower mathematics anxiety compared to those exposed to traditional teaching method ($p=0.003$), gamification ($p=0.043$) and collaborative gamification ($p=0.007$). There was no significant difference in mean score of mathematics anxiety between traditional teaching method, gamification and collaborative gamification. Thus, hypothesis 1 is not accepted.

Table 4. Post hoc analysis on the effect of teaching modalities on mathematics anxiety

Comparison	M_{diff}	SE	p
Collaborative learning vs. Traditional teaching method	-4.32	1.21	0.003
Collaborative learning vs. Gamification	-3.09	1.13	0.043
Collaborative learning vs. Collaborative gamification	-3.97	1.20	0.007
Gamification vs. Traditional teaching method	-1.23	1.17	1.000
Gamification vs. Collaborative gamification	-0.87	1.16	1.000
Collaborative gamification vs. Traditional teaching method	-0.35	1.24	1.000

Note: mean difference indicates the difference between the first and second group listed; positive values indicate higher score for the first group. $p < 0.05$ considered statistically significant (Bonferroni post hoc test).

3.2.2. Mathematics intrinsic motivation

As shown in the post-hoc analysis in Table 5, participants exposed to gamification had significantly higher mathematics intrinsic motivation compared to traditional teaching method ($p=0.001$), collaborative learning ($p=0.001$) and collaborative gamification ($p=0.030$). There was no significant difference in mean score of mathematics intrinsic motivation between traditional teaching method, collaborative learning and collaborative gamification. Thus, hypothesis 2 is not accepted.

Table 5. Post hoc analysis on the effect of teaching modalities on mathematics intrinsic motivation

Comparison	M_{diff}	SE	p
Gamification vs. Traditional teaching method	1.30	0.33	0.001
Gamification vs. Collaborative learning	1.29	0.32	0.001
Gamification vs. Collaborative gamification	0.94	0.33	0.030
Collaborative learning vs. Traditional teaching method	0.01	0.35	1.000
Collaborative learning vs. Collaborative gamification	-0.35	0.34	1.000
Collaborative gamification vs. Traditional teaching method	0.36	0.35	1.000

Note: mean difference indicates the difference between the first and second group listed; positive values indicate higher score for the first group. $p < 0.05$ considered statistically significant (Bonferroni post hoc test).

3.2.3. Mathematics achievement

The post-hoc analysis on mathematics achievement showed some interesting data, as seen in Table 6. Participants exposed to collaborative learning or gamification had significantly higher mathematics achievement compared to traditional teaching method ($p < 0.05$) and collaborative gamification ($p < 0.001$). No significant difference in mathematics achievement was found between collaborative learning and gamification ($p=1.000$). Interestingly, participants exposed to traditional teaching method had significantly higher mathematics achievement than participants exposed to collaborative gamification ($p < 0.001$), making collaborative gamification the least effective in improving mathematics achievement. Thus, hypothesis 3 is not accepted.

Table 6. Post-hoc analysis on the effect of teaching modalities on mathematics achievement

Comparison	M_{diff}	SE	p
Gamification vs. Traditional teaching method	1.50	0.56	0.048
Gamification vs. Collaborative gamification	6.85	0.55	<0.001
Collaborative learning vs. Traditional teaching method	1.58	0.58	0.044
Collaborative learning vs. Collaborative gamification	6.93	0.57	<0.001
Gamification vs. Collaborative learning	-0.08	0.54	1.000
Traditional teaching method vs. Collaborative gamification	5.35	0.60	<0.001

Note: mean difference indicates the difference between the first and second group listed; positive values indicate higher score for the first group. $p < 0.05$ considered statistically significant (Bonferroni post hoc test).

3.3. Mediating role of mathematics anxiety and mathematics intrinsic motivation

Two process macro model 4 were run to test if mathematics anxiety or mathematics intrinsic motivation mediates the relationship between teaching modalities and mathematics achievement. Dummy coding was used with traditional teaching method being the control group. Collaborative learning or gamification were treated as experimental groups in different analysis.

3.3.1. Mathematics anxiety

As seen from Table 7, when comparing collaborative learning and traditional teaching method, teaching modality significantly reduced mathematics anxiety ($\beta=-4.32$). Mathematics anxiety in turn significantly reduced mathematics achievement ($\beta=-0.10$). As the indirect effect of teaching modalities on mathematics achievement through mathematics anxiety was significant bias-corrected and accelerated confidence interval (BCA CI) [0.11, 0.87] and the direct effect of teaching modality on mathematics achievement remained significant ($p=0.010$) after controlling for mathematics anxiety, partial mediation was suggested. Thus, hypothesis 4 is accepted.

Table 7. Path coefficient for the mediation model of teaching modalities, mathematics anxiety, and mathematics achievement

Path	Model	β	t	p	BCA CI
a	Teaching modality→mathematics anxiety	-4.32	-3.56	<0.001	-
b	Mathematics anxiety→mathematics achievement	-0.10	-3.27	0.001	-
c'	Teaching modality→mathematics achievement	1.34	2.60	0.010	-
ab	Teaching modality→mathematics anxiety→mathematics achievement	0.45	-	-	[0.11, 0.87]

3.3.2. Mathematics intrinsic motivation

As seen from Table 8, when comparing gamification and traditional teaching method, teaching modality significantly increases mathematics intrinsic motivation ($\beta=1.30$), which in turn significantly increases mathematics achievement ($\beta=0.40$). As the indirect effect of teaching modalities on mathematics achievement through mathematics intrinsic motivation was significant (BCA CI [0.19, 0.90]), while the direct effect of teaching modality on mathematics achievement was not significant ($p=0.103$) after controlling for mathematics anxiety, full mediation is suggested. Thus, hypothesis 5 is partially accepted.

Table 8. Path coefficient for the mediation model of teaching modalities, mathematics intrinsic motivation, and mathematics achievement

Path	Model	β	t	p	BCA CI
a	Teaching modality→mathematics intrinsic motivation	1.30	3.91	<0.001	-
b	Mathematics intrinsic motivation→mathematics achievement	0.40	3.70	<0.001	-
c'	Teaching modality→mathematics achievement	0.80	1.64	0.103	-
ab	Teaching modality→mathematics intrinsic motivation→mathematics achievement	0.52	-	-	[0.19, 0.90]

3.4. Discussion

3.4.1. Prevalence of mathematics anxiety and mathematics intrinsic motivation

The prevalence of mathematics anxiety and mathematics intrinsic motivation collected in present study were identical to past studies, where students on average were reported to have moderate mathematics anxiety and mathematics intrinsic motivation [14]–[16], [42], [57]. However, the quarter of the students who reported high mathematics anxiety or low mathematics intrinsic motivation should not be ignored or overlooked. Such prevalence should be addressed to prevent worsening the vicious cycle between them and mathematics achievement.

3.4.2. Traditional teaching method

Participants exposed to traditional teaching methods in present study did not show improvement in mathematics anxiety and mathematics intrinsic motivation, supporting past research that indicated the limitation of traditional teaching method. Due to the teacher's authority and the fear of failure [22], students in traditional teaching method generally may not be dare to raise their questions or answers during the lesson. Furthermore, as mathematics is treated as a boring subject [30], such teacher-centered teaching method may not engage or sustain students' interest in mathematics learning.

Interestingly, in terms of mathematics achievement, those exposed to traditional teaching method had significantly higher scores compared to those exposed to collaborative gamification. Such findings may be attributed to the assessment focus in present study. The MAT used in present study tested only the first three levels in Bloom's taxonomy, namely remembering, understanding, and applying. Within this context, the features of having detailed explanation and drilling practices in traditional teaching method is well aligned with such low-order cognitive outcomes [18], [58], [59], therefore may have benefited students exposed to traditional teaching method in scoring high in the test. In addition, most of the students were familiar with this mainstream teaching method, therefore they may reduce the time needed to prepare the students for the lesson.

3.4.3. Collaborative learning

The results were aligned with past studies that reported the effectiveness of collaborative learning in improving mathematics achievement and reducing mathematics anxiety [28], [29], [60]–[62]. The results from mediation analysis further indicated that the improvement in mathematics achievement is because of the effect of collaborative learning in reducing mathematics anxiety. As a student-centered teaching method, collaborative learning may provide supporting setting for students to express their ideas comfortably [63], therefore reducing mathematics anxiety. In addition, the role of teacher moves to facilitator instead of instructor, therefore reducing the teacher authority that may cause students' mathematics anxiety. These features that reduce mathematics anxiety in turn improve students' mathematics achievement.

However, although participants in collaborative learning had higher mean scores in mathematics intrinsic motivation compared to those in traditional teaching method, the difference is not significant. Such results may be due to the task design of collaborative learning that focuses on problem solving only and does not aim to foster curiosity and enjoyment, one of the key points to improve intrinsic motivation. In addition, the imbalance participation such as students socially loaf during the group work may inhibit the collaborative learning from unleashing the full potential [64].

3.4.4. Gamification

Aligning with past studies, gamification in present study significantly improved mathematics achievement and mathematics intrinsic motivation [32]–[35], [65], [66]. Although it was hypothesized that mathematics intrinsic motivation would partially mediate the effect of gamification on mathematics achievement, further analysis revealed full mediation. This finding suggests that the influence of gamification on achievement operates primarily through its effect on mathematics intrinsic motivation. Game elements such as points, reward, and levels may create competence-boosting experiences and fulfill students' basic psychological needs for autonomy, competence, and relatedness [67]–[69]. As a result, these students may develop higher mathematics intrinsic motivation and engage more in mathematics related tasks, therefore boosting their mathematics achievement [13], [70]. Although other mechanisms such as engagement or self-efficacy may still contribute [71], [72], mathematics intrinsic motivation appears to be the dominant pathway in this context.

Despite its promising effect on mathematics intrinsic motivation, the gamification in present study did not reduce participants' mathematics anxiety significantly compared to the use of collaborative learning. Such results may be due to the competitive nature of gamification which may create time pressure or social comparison among the students [73]–[75], which may therefore balance the effect of fun environment in reducing mathematics anxiety. In addition, students may express negative emotion such as anxiety when they failed to achieve top position in gamification [39].

3.4.5. Collaborative gamification

While the effects of other teaching modalities obtained in present study were very alike with the past studies, the effects of collaborative gamification on mathematics learning are contradicted with the hypotheses and worth taking note on. Firstly, no significant improvement in mathematics anxiety and mathematics intrinsic motivation were observed when participants were exposed to collaborative gamification. Secondly, participants exposed to collaborative gamification reported significantly lower mathematics achievement compared to those exposed to traditional teaching method. Such findings may be explained using cognitive load theory.

Cognitive load theory explains that learning is limited by the capacity of human working memory, which can handle only a small amount of information at one time [76]. The mental effort required to process information is referred to as cognitive load. Cognitive load is divided into two main types: i) intrinsic load which arose from the complexity or difficulty of the learning material itself and ii) extraneous load which is created by the way information or tasks are presented [77], [78]. When the total cognitive load becomes too high, learners may experience cognitive overload, a state in which they struggle to organize and understand new information, making it difficult to store in long-term memory [79]. This overload is often suggested to reduce comprehension, lower engagement, and negatively affect academic performance [80].

In present study, collaborative gamification integrated elements from both gamification and collaborative learning, making the approach more complex than either method alone. Managing and understanding these elements may require students to process multiple pieces of information simultaneously, which can increase extraneous load [81]–[83]. Together with the inherently high intrinsic load related when solving mathematics tasks, students may experience cognitive overload, leaving fewer mental resources available to learn new concepts or apply previously learned knowledge. As a result, students exposed to this teaching modality may demonstrate lower mathematics achievement.

In addition, the focus on performance and competition in collaborative gamification may offset the benefit of collaborative learning in reducing mathematics anxiety. While collaborative learning provides

supportive and comfortable setting [63], collaborative gamification creates a competitive environment that may cause students to develop pressure to perform or fear of failure in a competitive environment [84], which enhance their mathematics anxiety. Furthermore, as collaborative gamification creates a time-pressure environment, high competence students may dominate the group discussions and show less consideration towards other classmates [85]. On the other hand, low competence students may be inhibited in participating freely or rely on high performing classmates to achieve top position [86], [87], therefore reducing the chance to develop mathematics intrinsic motivation.

4. CONCLUSION

The present study compared collaborative gamification with three existing teaching modalities to explore the effects of teaching modalities on mathematics anxiety, mathematics intrinsic motivation and mathematics achievement, and to examine if the effect on mathematics achievement was mediated by mathematics anxiety and mathematics intrinsic motivation. It was hypothesized that collaborative gamification is most effective in reducing mathematics anxiety and increasing mathematics intrinsic motivation, thereby improving mathematics achievement. However, the results indicated the opposite. These findings may be explained by the complex mechanisms involved in collaborative gamification and the counterbalance between collaborative learning and gamification elements.

Several limitations and future research suggestions were identified in present study. First, the study was conducted in only one Chinese Independent School in Malaysia, which may limit the generalizability of the findings due to relatively homogenous populations in terms of language, cultural background, and academic orientation. Future studies are encouraged to extend this research to other settings such as public schools where the student populations are more diverse. Second, as the teaching modalities were implemented by different mathematics teachers, teacher-related differences such as instructional enthusiasm, classroom management practices, or fidelity of implementation may have influenced the findings. However, the differences were minimized by providing adequate training, using same examples, practices, marking scheme for MAT, and total duration of the lessons. Third, the MAT in present study assessed only the first three levels of Bloom's taxonomy. Future research may include higher-order cognitive skills as well as 21st century skills acquisition such as communication, analytical and critical thinking skills, to provide a more comprehensive evaluation. Fourth, as interventions lasted only one week due to school administrative constraints, longitudinal follow-up studies are recommended to examine the long-term effects. Lastly, future research may identify the optimal ratio of collaborative and gamified elements in teaching modalities to prevent cognitive overload, and the appropriate timing to introduce such elements. In addition, hybrid models with fewer competitive elements may be explored to examine whether such designs can improve learning while minimizing the potential negative effects associated with excessive competition.

The study provides a comprehensive perspective on the effect of different teaching modalities on mathematics anxiety, mathematics intrinsic motivation and mathematics achievement. It supported the effectiveness of gamification in enhancing mathematics intrinsic motivation and collaborative learning in reducing mathematics anxiety. It also emphasizes the importance of addressing students' affective and cognitive needs instead of expanding the syllabus alone as the means to improve mathematics achievement.

The limited effectiveness of collaborative gamification highlights the need for careful instructional design. While each method independently supports motivation or reduces anxiety, integrating them may not yield better results and may even introduce challenges that diminish overall effectiveness. Educators should be cautious against overloading lessons with excessive elements, as it may reduce practice time or lead to cognitive overload, hindering learning effectiveness. When necessary, scaffolding strategies may be implemented when introducing new teaching modalities to reduce the excessive mental efforts needed to process unfamiliar learning instructions. Lastly, the framework of collaborative learning and gamification used in present study may serve as a guideline for educators designing the related teaching modalities.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : Conceptualization

M : Methodology

So : Software

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R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

INFORMED CONSENT

The authors have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The study adhered to ethical standards in research involving human participants. Approval was granted by the university's Ethics Committee prior to the commencement of the study.

DATA AVAILABILITY

The data that supports the findings of this study are available on request from the corresponding author, [JWY]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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