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Development of GeoExplorer: A Gamification Platform Utilizing Constructivist Approach to Alleviate Mathematical Anxiety

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ABSTRACT

Mathematics serves as a foundational skill essential for various technical disciplines within polytechnic institutions, significantly contributing to the development of students' mathematical problem-solving capabilities. Nevertheless, a preliminary investigation among architecture students indicated a pronounced prevalence of mathematical anxiety, which adversely affects their engagement with mathematical concepts and undermines their academic performance. In response to this critical issue, GeoExplorer was developed as an innovative digital platform that amalgamates gamification techniques with a constructivist learning approach aimed at mitigating mathematical anxiety. This research aims to evaluate the efficacy of GeoExplorer in reducing mathematical anxiety and to assess students' perceptions of the platform's effectiveness. The study sample comprised 29 first-semester architecture diploma students, selected through purposive sampling. A quantitative research design was employed, incorporating pre- and post-intervention anxiety questionnaires, mathematics test and a perception survey to gauge students' experiences, expectations, and satisfaction with GeoExplorer. A Paired Samples t-test was utilized to analyze variations in mathematical anxiety, concentrating on three specific dimensions: Test Anxiety, Numerical Anxiety, and Mathematics Classroom Anxiety. The results demonstrated a statistically significant reduction in overall mathematical anxiety post-intervention, with notable enhancements across all three dimensions. Furthermore, students conveyed positive perceptions of GeoExplorer, underscoring its effectiveness in fostering engagement and enriching the overall learning experience. This study concludes that GeoExplorer is a valuable tool for alleviating mathematical anxiety and supporting constructivist learning, suggesting its potential to enhance mathematical performance among architecture students in polytechnic institutions.

1. Introduction

Mathematics education plays a crucial role in the Malaysian education system, particularly within polytechnics where the subject is a foundational component for various technical and vocational programs. Despite its importance, mathematics is often perceived as a difficult subject by students, leading to learning challenges that hinder academic achievement. In the polytechnic context,

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especially among architecture students, these challenges are further magnified due to the abstract nature of mathematical concepts and their application to spatial reasoning, geometry, and structural analysis [1-3]. Geometry is one of the topics that architecture students often find challenging. This difficulty arises primarily because geometry requires a high level of spatial reasoning, a skill essential in the field of architecture [4,5]. Students must visualize complex shapes, understand their properties, and apply these concepts to real-world structures. Furthermore, architectural geometry often involves abstract mathematical concepts like angles, planes, and three-dimensional forms, which are not only hard to grasp but also to apply practically in design work [2,6-9]. The integration of these abstract geometric principles with architectural design, construction, and visualization requires both theoretical knowledge and practical problem-solving abilities. Many students struggle with this dual demand, contributing to their overall difficulty with the subject [4,5,8,10]. This challenge is compounded by the pressure of using these concepts in technical drawings and models, where precision and accuracy are critical, thus amplifying mathematics anxiety among architecture students [9-12].

One significant issue contributing to these challenges is mathematics anxiety, a widespread phenomenon where students experience feelings of tension, apprehension, and fear when confronted with mathematical tasks [13-17]. Research indicates that mathematics anxiety not only affects students' confidence but also impairs their ability to understand and apply mathematical concepts effectively [18-22]. This is particularly evident in architecture students, whose success in areas such as geometry and technical drawing relies heavily on mathematical competence. As a result, their academic performance is often compromised, leading to lower retention rates in related coursework. Mathematics courses, particularly elementary mathematics, are foundational for architecture students at polytechnics. The first-semester Elementary Mathematics course is specifically tailored to address the unique needs of these students, recognizing the essential role those mathematical principles play in architecture. Various initiatives have been introduced to enhance the mathematical proficiency and academic performance of architecture students throughout their studies [1,16,23]. Despite its significance, many students perceive mathematics courses as difficult and complex, which can hinder their ability to succeed. A significant number of architecture students struggle to understand the relevance of certain mathematical concepts to their discipline, leading to the development of mathematical anxiety. This emotional barrier often undermines their problem-solving abilities and negatively impacts their overall performance in mathematics courses [16,24-27]. Research shows that students in STEM fields, including architecture and engineering, frequently experience heightened levels of stress, depression, and anxiety due to the rigorous mathematical demands [28-30]. To address these challenges, gamification has emerged as a promising pedagogical approach. Gamification integrates game mechanics into non-game environments that can reduce mathematics anxiety by fostering a more interactive and engaging learning environment, allowing students to approach mathematical problems in a playful and less intimidating manner [31-34]. Studies shows gamification is consistent with the constructivist learning theory, which emphasizes that learners actively build their understanding through hands-on experiences and personal reflection, rather than simply absorbing information passively [3,35-38].

2. Theoretical Framework

GeoExplorer is a gamification platform designed to reduce mathematics anxiety by leveraging the principles of Constructivist Learning Theory [37,39]. According to this theory, learning is most effective when students actively engage with content, construct new knowledge based on their prior experiences, and reflect on these experiences to deepen understanding. Unlike traditional models of passive learning, Constructivist Learning emphasizes that students must play an active role in their learning process, integrating new information into their pre-existing knowledge [36,40,41]. A cornerstone of Constructivist Theory, active learning posits that students learn best when they engage directly with the material. GeoExplorer applies this principle by embedding mathematical concepts within interactive challenges, quizzes, and puzzles. This gamified environment encourages students to interact with mathematical problems actively, rather than passively receiving information. By solving puzzles and overcoming challenges, students can explore hands-on concepts, fostering a deeper comprehension of the underlying mathematical ideas (see Figure 1). Constructivism emphasizes the importance of building new knowledge on learners' existing understanding. In GeoExplorer, the platform is structured progressively, with each level introducing concepts that build upon those introduced in previous stages. This sequential progression allows students to connect new mathematical ideas with their prior knowledge, reinforcing their understanding and facilitating more meaningful learning experiences [36]. Gradual development ensures that students are continuously challenged, but in a way that remains rooted in familiar concepts, reducing cognitive overload and enhancing retention. Social learning is another vital component of Constructivist Theory. Learning is enhanced when students collaborate, share insights, and engage in discussions with peers. GeoExplorer integrates social interaction by incorporating collaborative challenges and group tasks, encouraging students to work together and exchange ideas.

This collaborative element not only reinforces the social dimensions of learning but also encourages deeper cognitive engagement, as students learn to articulate their reasoning and consider alternative perspectives. Scaffolding is a teaching strategy often used in Constructivist approaches, where learners are provided with temporary support to help them navigate challenging concepts. As students gain confidence and proficiency, these supports are gradually removed, promoting independence. GeoExplorer implements this by offering tiered levels of difficulty. Initially, students receive more guidance and assistance to build foundational knowledge. As they progress, the complexity of tasks increases, and the scaffolding is gradually withdrawn, allowing students to solve problems independently and master more complex mathematical concepts [32,42,43]. By combining these core principles of Constructivism with gamification, GeoExplorer transforms how students experience mathematics. It makes the subject more accessible, interactive, and enjoyable, fostering an active learning environment that reduces mathematics anxiety, particularly for polytechnic architecture students [37,44]. This study aims to assess the effectiveness of the development of GeoExplorer, a gamification platform with constructivist approach on reducing mathematics anxiety particularly in the context of polytechnic architecture students and to explore student perceptions of the platform.

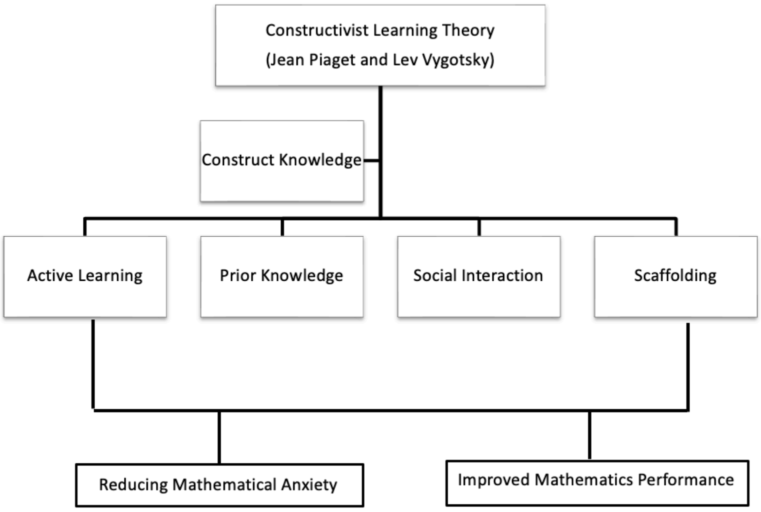

Fig. 1. Thereotical framework

3. Literature Review

The literature review begins by examining the mathematical learning difficulties commonly faced by higher education students, followed by a look at how mathematical anxiety significantly impacts their academic performance. It then explores the potential of gamification and the constructivist approach to improve understanding and engagement, particularly when combined in a gamified learning environment (refer Figure 2). Mathematics learning difficulties among higher education students are widespread and multifaceted, often arising from abstract concepts, cognitive overload, and insufficient foundational skills. These challenges encompass both academic and psychological dimensions, as students frequently experience frustration, diminished self-efficacy, and avoidance behaviors when faced with mathematical tasks [25,45,46]. These learning difficulties, particularly in disciplines that necessitate advanced problem-solving abilities and abstract reasoning, contribute to a cycle of negative perceptions regarding mathematics, ultimately impairing students' academic performance and persistence in STEM-related fields. The rigors of higher education, with their heightened expectations for mathematical competence, can exacerbate these difficulties, resulting in disengagement and reduced motivation among students who feel inadequately prepared or anxious about their capabilities [47,48].

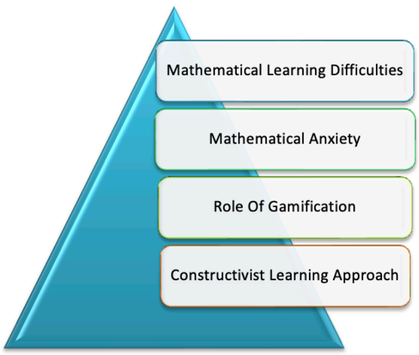

Fig. 2. Review of literature

A significant issue arising from these learning difficulties is mathematics anxiety, a specific form of anxiety that affects a substantial proportion of college students and hinders their academic performance and persistence [49,50]. Students who experience mathematics anxiety are more likely to struggle with conceptual understanding, mental arithmetic, and problem-solving tasks, creating a cyclical relationship where anxiety and poor performance mutually reinforce each other highlighting the urgent need for effective interventions to mitigate this issue. In recent years, gamification has emerged as a promising strategy to alleviate mathematics anxiety and promote engagement among higher education students [31,51]. Gamified learning environments improved motivation and reduced mathematics anxiety, as students could engage with content in both structured and flexible manners. In the realm of mathematics education, constructivist methods can effectively assist students in deconstructing abstract concepts into more comprehensible components through personalized, scaffolded learning experiences. digital platforms inspired by constructivist principles improved mathematical understanding by facilitating exploration and interaction with mathematical content, thereby promoting deeper cognitive engagement and confidence [35-37]. Constructivist learning environments significantly enhanced problem-solving skills and fostered self-efficacy, both of which are particularly beneficial for students experiencing high levels of mathematics anxiety. GeoExplorer platform aspires to integrate gamification and constructivist learning principles to address the unique challenges faced by higher education students grappling with mathematics anxiety and learning difficulties [30,52,53]. Thus, this study intends to evaluate the effectiveness of GeoExplorer in mitigating mathematics anxiety, enhancing engagement, and cultivating a positive attitude toward mathematics among higher education students, thereby contributing to the expanding body of research on gamified constructivist learning solutions.

4. Methodology

This study adopts a quantitative approach to evaluate the effectiveness and user perception of GeoExplorer, a gamification platform aimed at reducing mathematical anxiety. The sample comprised 29 first-semester diploma students in architecture at a polytechnic institution [43]. Although the sample size is relatively small, it is suitable for this exploratory study, which focuses on assessing the effectiveness of a specific pedagogical intervention. Prior research supports the validity of small sample sizes in educational studies, particularly when targeting specific student groups and contexts [54,55]. Participants were selected through purposive sampling, ensuring their relevance as the target user group for GeoExplorer. Informed consent was obtained from all participants prior to data collection, adhering to ethical research practices. GeoExplorer is a web-based platform incorporating interactive games and challenges aimed at reinforcing mathematical concepts, specifically in geometry, while alleviating anxiety. The study evaluated the platform's impact on both mathematical performance and anxiety levels. The primary data collection tools were a Mathematical Anxiety Questionnaire and a Mathematics Test. Mathematical Anxiety Questionnaire:

This instrument, adapted from established scales consists of 20 Likert-scale items (1 = Strongly Disagree to 5 = Strongly Agree) designed to measure students' mathematical anxiety across multiple dimensions. [56-58]. The questionnaire was validated by an expert panel specializing in mathematics, education, and child development psychology to ensure clarity, relevance, and alignment with the target population. Cronbach's alpha for internal consistency was >0.65, indicating satisfactory reliability [59-61]. The Mathematics Test, consisting of 15 multiple-choice questions, was developed to assess students' understanding of key mathematical concepts such as geometry, algebra, and arithmetic. The test was administered both as a pre-test (prior to using GeoExplorer) and a post-test (after using the platform) to measure learning outcomes.

The pre-test established a baseline, while the post-test results gauged the platform's effectiveness. The test was reviewed and validated by content experts to ensure it aligned with learning objectives and was suitable for the student population [51,62-65]. To explore student perceptions of GeoExplorer, a Perception Questionnaire was utilized [61,66,67]. This instrument, consisting of 20 questions divided into three categories Expectation, Experience, and Satisfaction provided comprehensive insight into how students viewed the platform in terms of meeting their learning needs, facilitating their experiences, and overall satisfaction with its effectiveness in helping them understand geometric concepts (refer Table 1).

Table 1
Category and description of perception questionnaire

Category	Description
Expectation	Refer to students' initial beliefs and anticipations before using GeoExplorer.
Experience	Refer to students' actual experiences while engaging with the GeoExplorer.
Satisfaction	Refer to students' overall satisfaction after using GeoExplorer.

Figure 3 illustrates the phases of the ADDIE Model used in the development of GeoExplorer, which serves as the foundation for the platform's implementation methodology, ensuring that it achieves its intended objectives. ADDIE model played a pivotal role in the development of GeoExplorer, ensuring that the platform was both practical and responsive to the needs of students [68-71]. By following the structured approach of Analysis, Design, Development, Implementation, and Evaluation, the GeoExplorer a gamification platform was developed to alleviate mathematical anxiety but also enhances the learning experience through innovative gamification.

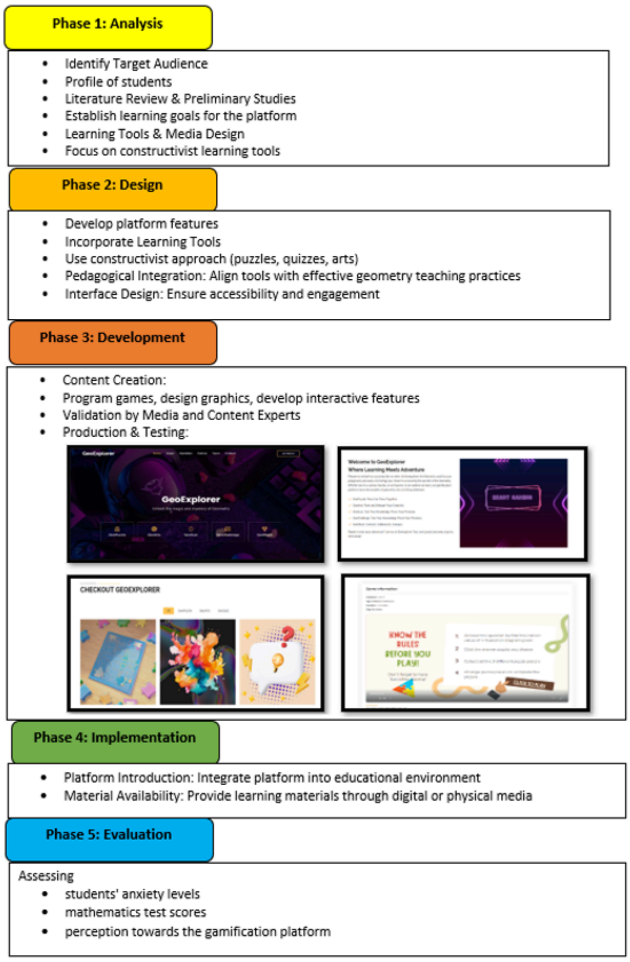

Fig. 3. Phases of the ADDIE Model

5. Results

5.1 Mathematics Anxiety Levels

According to Figure 4, among the 29 students surveyed, nine (31%) initially reported high levels of mathematical anxiety, which decreased to five students (17.2%) following the introduction of GeoExplorer. Additionally, 21 students (47%) were found to have moderate levels of math anxiety, while 13 students (29%) experienced low levels. Notably, only one student (2%) reported very low levels of math anxiety. Research indicates that math anxiety is a common issue among students learning mathematics in the classroom [49,57,72]. These results highlight the presence of math anxiety among Architecture students and align with the general occurrence of anxiety in mathematics education. The levels of mathematical anxiety were further analyzed through Paired Samples t-Test for analyzing changes in anxiety, focusing on specific components such as test anxiety, numerical anxiety, and mathematics classroom anxiety.

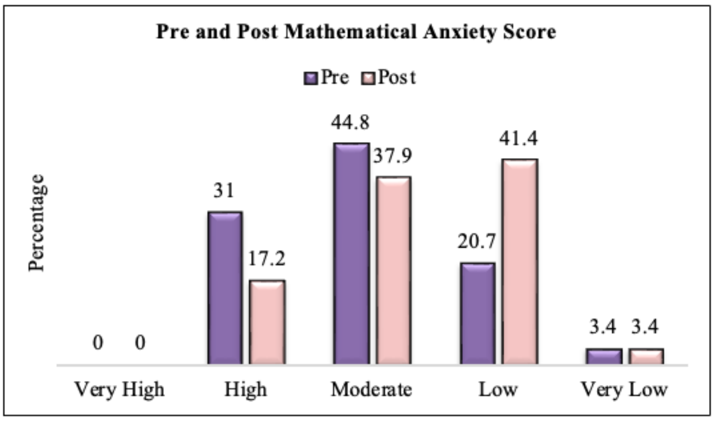

Fig. 4. Pre and post maths anxiety score based on maths anxiety levels

3.1.1 Paired samples t-Test on test anxiety, numerical anxiety, and mathematics classroom anxiety

The results of the t-tests indicate statistically significant reductions in both Test Anxiety and Mathematics Classroom Anxiety following the intervention with GeoExplorer. Specifically, for Test Anxiety, the mean difference between pre- and post-scores was 0.33241, with a t-value of 2.490 and a p-value of 0.019, indicating a statistically significant reduction ($p < 0.05$). Similarly, Mathematics Classroom Anxiety showed a mean difference of 0.29483, with a t-value of 2.378 and a p-value of 0.024, also demonstrating statistical significance (refer Table 2). These findings suggest that the intervention had a meaningful impact in alleviating anxiety related to both test performance and the classroom learning environment. However, for Numerical Anxiety, the mean difference was 0.27138, with a t-value of 1.960 and a p-value of 0.060. Since the p-value exceeds the 0.05 threshold for statistical significance, this result suggests that the observed reduction in numerical anxiety may have occurred by chance and does not provide conclusive evidence of the intervention's effectiveness in this domain. It is important to note that while the p-value is greater than 0.05, it is still marginally close to the significance threshold, suggesting that further investigation could be warranted. In educational research, especially within STEM fields, it is not uncommon to encounter p-values near the threshold, such as $p = 0.060$, which while not meeting the conventional standard for statistical significance, may still offer valuable insights when considered in context [28,59]. In such cases, researchers often argue that small deviations from the $p < 0.05$ cutoff should not entirely discount the potential impact of the intervention, particularly in exploratory studies or with small sample sizes. It is possible that the intervention had some influence on numerical anxiety, but the effect was not strong enough to reach statistical significance in this sample. This outcome aligns with findings from other studies where near-threshold p-values, although not statistically significant, have been interpreted as indicative of potential trends that may warrant further exploration [73,74]. Thus, while the intervention successfully reduced Test Anxiety and Mathematics Classroom Anxiety, the effect on Numerical Anxiety remains inconclusive. Future research could explore this further by using a larger sample size or by modifying the intervention to address numerical anxiety more directly [59,75].

These findings align with the constructivist approach, which emphasizes creating an active, supportive learning environment where students can build confidence and mastery incrementally, thereby reducing anxiety. The statistically significant reduction in Test Anxiety and Mathematics Classroom Anxiety following the use of GeoExplorer suggests that constructivist-based gamification can effectively ease anxieties associated with high-stakes testing and classroom performance by focusing on active, hands-on learning rather than traditional, passive approaches. Constructivist theory posits that anxiety can be reduced when students are active participants in their learning journey, drawing on prior knowledge and gradually advancing through scaffolded challenges. GeoExplorer's design, which allows students to engage directly with mathematical concepts through interactive tasks, likely provided a more secure and supportive environment that mitigated test-related stress. This scaffolding, a central tenet of constructivism, allows students to start with simpler tasks and progress to more challenging ones, reinforcing their knowledge base and bolstering their confidence elements essential in reducing test anxiety. However, the less conclusive impact on Numerical Anxiety highlights a potential area for deeper application of constructivist strategies. Numerical anxiety often stems from foundational gaps in understanding, which may require targeted interventions that emphasize Prior Knowledge reinforcement and Social Interaction. Collaborative problem-solving activities, which GeoExplorer partially employs, can enhance students' comfort with numerical challenges by normalizing mistakes as part of the learning process and fostering a supportive peer-based environment. In essence, the findings underscore that constructivist-based learning environments, especially those enhanced by gamification, can significantly alleviate certain aspects of math-related anxiety. These reductions in anxiety illustrate how active, structured, and socially engaging learning platforms like GeoExplorer, grounded in constructivist principles, can positively reshape students' emotional experiences in learning mathematics.

Table 2
Paired samples t-Test

Component	Mean	Std Dev	t	df	Sig. (2-tailed)
Test Anxiety	0.33241	0.71889	2.490	29	.019
Numerical Anxiety	0.27138	0.7457	1.960	29	.060
Mathematics Classroom Anxiety	0.29483	0.66759	2.378	29	.024

5.1.2 Spearman's rho correlation level mathematics anxiety score and mathematics test score

The Spearman's rho correlation analysis results, demonstrating significant negative correlations between anxiety levels and test scores both before and after the intervention, offer insights that align with the principles of the constructivist approach. Constructivist theory emphasizes that learning is an active, reflective process where learners construct knowledge through meaningful experiences within a supportive environment. Anxiety is understood in this framework as a critical affective factor that can act as a barrier to deep learning by impeding the learner's ability to engage fully and reflect effectively, both of which are essential to knowledge construction. The observed negative correlations suggest that high anxiety levels impair students' test performance, aligning with constructivist views on the impact of affective factors on learning outcomes [19,28,76,77].

Table 3
Spearman's rho

Correlation	Test Score	Anxiety Score	Sig. (2-tailed)	N
Pre-Test Score	1.000	-0.680**	0.000	29
Pre-Anxiety Score	-0.6860**	1.000	0.000	29
Post-Test Score	1.000	0.686**	0.000	29
Post-Anxiety Score	0.686**	1.000	0.000	29

5.1.3 Student perception score on GeoExplorer

Figure 5 illustrates that 58.6% of students perceived GeoExplorer as meeting their expectations, suggesting that the platform aligns well with their anticipated experiences of a gamified learning tool. This alignment can be attributed to GeoExplorer's design, which presents mathematical concepts in an engaging and interactive manner, especially benefiting students who find conventional teaching approaches less effective for their learning stylesist perspective, GeoExplorer's approach supports active, student-centered learning, allowing students to construct knowledge by actively engaging with mathematical concepts in a low-stress, enjoyable environment. This setting helps reduce math anxiety and offers students the freedom to explore concepts at their own pace, which is integral to constructivist principles of knowledge building [32,33]. While a majority of students reported that the platform met their expectations, the remaining 41.4% expected a more comprehensive experience. This discrepancy points to an opportunity to further tailor GeoExplorer to a broader range of learner needs, enhancing the platform's alignment with constructivist ideals by better facilitating individualized learning paths. Insights into specific expectations can guide refinements, such as offering personalized support, adjusting content difficulty levels, or integrating features that allow students to track their learning progress. By catering to these individualized needs, GeoExplorer can more effectively promote the learner autonomy and self-directed exploration that are central to constructivist learning environments. Furthermore, 58.6% of students reported a positive learning experience with GeoExplorer, indicating that the platform effectively facilitated learning through gamification. This gamified approach aligns well with constructivist principles by fostering an interactive and supportive environment, where students are encouraged to explore mathematical concepts without the high stakes of traditional assessments. The positive response also suggests that GeoExplorer reduced students' stress levels and made learning mathematics more accessible, as constructivist methods advocate for creating low-anxiety learning spaces that support meaningful engagement. Notably, while 52.2% of students expressed satisfaction, a significant portion expressed mixed or negative feelings about their overall experience. This division may stem from factors such as the platform's user interface, content complexity, or perceived engagement levels. Constructivist theory emphasizes the importance of a supportive, adaptable learning environment, suggesting that future improvements could focus on customizing the platform's design to meet diverse learning preferences. To enhance satisfaction and construct a more inclusive learning experience, it would be beneficial to gather feedback from the less satisfied students to identify specific areas for improvement [31,51,69]. Potential enhancements might include increasing the interactivity of learning modules, offering adaptable content based on individual skill levels, and incorporating tools that support reflection, allowing students to develop metacognitive skills as they learn. These adjustments would align with constructivist principles by enabling GeoExplorer to support not only cognitive learning goals but also the emotional and self-regulatory skills crucial for effective and autonomous learning.

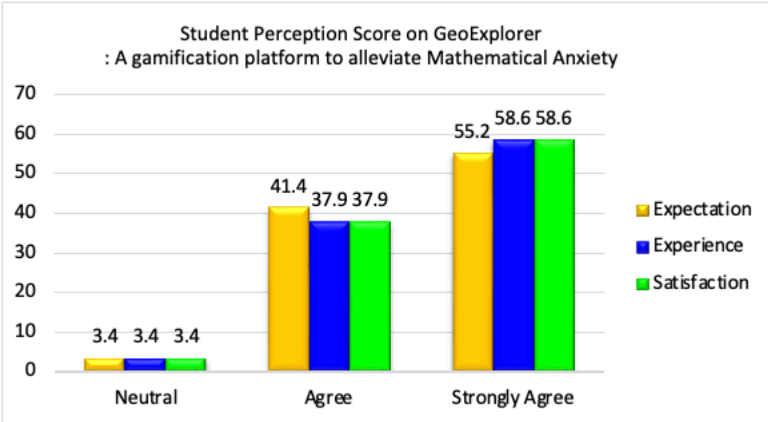

Fig. 5. Student perception score

6. Conclusions

GeoExplorer creates a supportive environment where students can explore and master geometric concepts at their own pace through the integration of interactive and engaging elements in games such as GeoPuzzle and Geo Arts. he platform's thoughtful design emphasizes gradual progression through levels while providing real-time feedback, which not only enhances students' understanding of geometry but also builds their confidence in mathematical problem-solving. The research findings underscore GeoExplorer's effectiveness in reducing mathematics anxiety among participants, directly addressing the research objective of improving student understanding and learning outcomes in mathematics. Specifically, the positive impact on students' anxiety levels illustrates how the gamified approach fosters a more relaxed and enjoyable learning atmosphere, enabling students to overcome their fears and hesitations regarding mathematics. This success emphasizes the critical role that integrating technology and gamification can play in educational practices, demonstrating that innovative solutions grounded in sound pedagogical principles can lead to substantial improvements in educational outcomes.

However, while the findings are promising, it is essential to acknowledge certain limitations that could affect the generalizability and reliability of the results. First, the study involved a limited sample size, which may not adequately represent the broader population of students, potentially leading to skewed results. A larger and more diverse sample in future studies could enhance the generalizability of the findings. Second, the lack of longitudinal data presents another limitation; the effectiveness of educational interventions like GeoExplorer may require long-term assessment to ascertain sustained impacts on students' mathematical performance and anxiety levels. Short-term studies might not fully capture the long-lasting effects of such interventions [54,55,78]. Additionally, the absence of a control group makes it challenging to determine whether the observed improvements were solely due to the GeoExplorer platform or influenced by external factors. Future research should incorporate a control group that does not use the platform, allowing for a more isolated assessment of the intervention's effects. Furthermore, the reliance on self-reported measures of anxiety and performance may introduce bias, highlighting the need for objective assessments, such as standardized tests or performance metrics, to provide a more accurate evaluation of the platform's effectiveness. To improve future studies, several recommendations should be considered. Increasing the sample size and diversity will provide more comprehensive insights, while implementing a longitudinal design will facilitate tracking changes in mathematical anxiety and performance over time. Incorporating objective assessments alongside self-reported measures will offer a more balanced evaluation of GeoExplorer's impact on students' mathematical skills and anxiety levels. Strengthening the theoretical framework by elaborating on the gamification and constructivist approaches used in GeoExplorer could further enrich the research context and connect these theories to the specific challenges in mathematics education. By addressing these limitations and implementing the suggested improvements, future research can provide more robust evidence regarding the effectiveness of GeoExplorer in alleviating mathematical anxiety and enhancing learning outcomes. In conclusion, GeoExplorer exemplifies how innovative educational tools can effectively enhance student mathematical anxiety and mastery of mathematical concepts, ultimately contributing to a more positive and confident learning experience among polytechnic architecture students. [14,46,79,80].

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