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The Synergy of Augmented Reality with the Flipped Classroom Structure and Its Impact on Learning Engagement Among Higher Education Students

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Abstract

The synergy between augmented reality (AR) and the flipped classroom model plays a pivotal role in developing modern learning methods and enhancing student engagement within university learning environments. Higher education learning environments often involve cognitive and skill-based challenges that require a high degree of active and continuous student engagement in educational activities. Therefore, this study aimed to examine the impact of AR synergy with the flipped classroom model on increasing student engagement in higher education by comparing the effectiveness of a learning environment based on AR synergy with one based solely on the flipped classroom model. The study employed a quasi-experimental design with two experimental groups of 60 preparatory year students at University of Jeddah, randomly assigned to each group. The first experimental group (30 students) studied within a learning environment based on AR synergy and the flipped classroom model, using the Edpuzzle platform for pre-class activities and the Zappar application for implementing AR activities within the classroom. The second experimental group (30 students) studied the same content using the traditional flipped classroom model with regular classroom activities, without the use of augmented reality. The Learning Engagement Scale, with its three dimensions (behavioral, cognitive, and affective), was used after its validity and reliability were verified to measure the impact of the proposed model on enhancing student engagement. The results showed that the group studying in the synergistic environment combining augmented reality and flipped classrooms outperformed the other group in all dimensions of engagement, reflecting the effectiveness of this integration in raising levels of active participation, attention, motivation, and positive engagement with the learning process. These results indicate that the synergy between augmented reality and flipped classrooms represents a promising approach in developing university teaching strategies, as it integrates prior self-directed learning with immersive, interactive classroom experiences, thus contributing to the creation of stimulating learning environments that foster deep and sustained engagement in learning.

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Introduction

The flipped classroom is a modern educational model that reverses the traditional roles of learning inside and outside the classroom (Mishall et al., 2025). This model relies on making core theoretical content available to students via digital media for individual at-home learning (She & Lai). Meanwhile, valuable classroom time is dedicated to interactive activities, practical application, problem-solving, and collaborative discussions (Zaki et al., 2024). The flipped classroom technique aims to promote active engagement, develop higher-order thinking skills, and transform the teacher's role into that of a facilitator and guide in the learning process (Li et al., 2024).

Recent years have witnessed a surge in research evaluating the effectiveness of the flipped classroom model in higher education. Several studies have aimed to analyze its impact on learning outcomes and students' academic behavior. In this context, a systematic review demonstrated that the flipped classroom model outperforms traditional methods in enhancing academic grades and skills outcomes, particularly in disciplines requiring practical application (Algarni, 2025). Similarly, a case study conducted at Ajman University revealed statistically significant differences favoring the experimental group that used the flipped classroom model, confirming a clear improvement in academic achievement, motivation, and engagement in learning among undergraduate students (Eltahir & Alsalhi, 2025). Furthermore, the study by Hu et al. (2025) provides recent empirical evidence of the superiority of the flipped classroom model, supported by the TikTok application, over traditional methods in improving academic performance and design skills (theoretical knowledge, creativity, and practical ability) among students at the College of Fine Arts.

The successful transition to flipped classrooms requires a heightened focus on the quality of the second phase of these classes: interaction time within the classroom. In this context, integrating augmented reality (AR) is a procedural necessity to maximize added educational value (Dai & Kang, 2025). AR provides a unique immersive environment that enables higher education students to transcend the physical limitations of engaging with complex and abstract concepts by projecting interactive digital objects onto the real world (Aygün & Çelik, 2025). This integration of AR with the flipped classroom structure ensures more effective use of instructor time, transforming classroom discussions into practical applications and real-time simulations. This, in turn, enhances student engagement and directly supports their acquisition of the practical and analytical skills that are central to higher education goals. In this context, the study by Khodabandeh et al. (2025) The study emphasized the necessity of integrating augmented reality into active learning models such as flipped classrooms. The results demonstrated a clear advantage for the experimental group that utilized augmented reality within the flipped classroom context in improving participants' language performance. The significance of this study lies in highlighting the pivotal role of augmented reality in the interactive phase (phase two) of the flipped classroom model, thus supporting the need for immersive classroom experiences to ensure the practical consolidation of self-learned theoretical concepts.

Based on the foregoing, while recent educational literature emphasizes the overall effectiveness of the flipped classroom model in higher education and its improvement of academic engagement, and despite the growing interest in augmented reality (AR) technologies as a transformative learning tool, there remains a clear scarcity of

empirical studies specifically focusing on the combined and synergistic impact of integrating AR technology within the interactive phase (in-class activities) of the flipped classroom structure. Most previous studies have addressed either the flipped classroom model or AR in isolation, or have focused on blended learning as a broader framework, creating a knowledge gap regarding how this systematic and tailored integration affects learning engagement patterns, particularly in higher education contexts that demand in-depth practical applications. Therefore, this study seeks to bridge this gap by investigating the direct impact of AR's synergy with the flipped classroom structure on student learning engagement. Accordingly, the current study aims to:

The current study aims to:

1. Measure the effectiveness of an educational program designed according to the flipped classroom model, enhanced with augmented reality, in developing learning engagement levels among higher education students.
2. Detect any statistically significant differences in learning engagement attributable to the use of the proposed model compared to the traditional method (control group).

The study's hypothesis is based on the existence of a significant positive effect of integrating augmented reality with flipped classrooms. The statistical hypothesis can be formulated as follows: There are statistically significant differences between the mean scores of students in the experimental group (flipped classrooms enhanced with augmented reality) and the control group (flipped classrooms without augmented reality) in the post-test of learning engagement, in favor of the experimental group that used the flipped classroom program enhanced with augmented reality.

Literature Review

Synergy of Augmented Reality with the Flipped Classroom

The core philosophy of the flipped classroom model is based on repurposing class time so that it is not consumed by traditional theoretical lectures, but rather invested in providing targeted support to learners and helping them practice advanced learning strategies through engaging and enjoyable interactive activities (DeLozier & Rhodes, 2017). This model allows students the opportunity to apply their knowledge independently and activate higher-order thinking skills instead of simply receiving information directly from the teacher (Lai & Hwang, 2016). Flipped learning also relies primarily on preparing learners in advance by providing learning materials before class time so that students can study them independently at home or in any other independent learning context. Class time is then dedicated to deeper discussions and richer educational interaction about the content (Şengel, 2016).

In contrast, augmented reality (AR) is one of the most prominent emerging technologies that enriches interactive learning environments by integrating three-dimensional virtual elements into the real world, enabling learners to visualize and interact with abstract concepts in multi-sensory ways (Alhalafawy & Zaki, 2024). Recent studies confirm that AR contributes to heightened attention, increased motivation, and active engagement in educational tasks through immersive experiences that promote deep cognitive processing and social interaction within learning

environments (Chen et al., 2024; García-Robles et al., 2024; Najmi et al., 2023; Shen et al., 2022).

Among the studies that targeted the synergy between flipped classrooms and augmented reality, Antoniou et al. (2024) aimed to employ an augmented reality-based learning environment within a flipped classroom model for first-year medical students to enhance their knowledge of cardiopulmonary resuscitation (CPR). The study aimed to assess knowledge acquisition and learners' perceptions, and the results showed a clear improvement in achievement after the activity, along with high levels of motivation, despite some technical and organizational challenges. Campos-Mesa et al. (2022) aimed to analyze the motivation of university students during the period of in-person learning during the COVID-19 pandemic, according to the type of educational material used—traditional videos or augmented reality videos—within the flipped classroom methodology. The study aimed to measure motivation, and the results showed that students in the group that used augmented reality content exhibited significantly higher levels of motivation compared to traditional videos, confirming the effect of immersive content in enhancing motivation and engagement in active learning environments. Ferrer-Torregrosa et al. (2016) This study aimed to compare the effectiveness of three types of educational media in teaching anatomy within a flipped classroom model: visual notes, videos, and augmented reality applications. The study analyzed the time spent, learning acquired, metacognitive perception, and perceptions of future use of augmented reality. The results showed that the augmented reality group outperformed the other two groups in all dimensions, achieving the highest average test score (7.19) compared to videos (6.54) and notes (5.60). This reflects the role of augmented reality in enhancing cognitive efficiency and developing independent learning. Khodabandeh's (2025) study aimed to investigate the effect of the ARLOOPA augmented reality application on the learning of countable and uncountable vocabulary among English as a foreign language students in a flipped classroom context. This study aimed to compare the performance of two groups of female students in the flipped classroom model: one online and the other face-to-face, after 12 learning sessions. The results showed the superiority of the group that studied using the online flipped classroom model, indicating that combining flipped classrooms with augmented reality contributes to enhancing vocabulary acquisition and long-term retention. The quasi-experimental study by Khazaie and Ebadi (2025) explored the feasibility of employing flipped classrooms supported by augmented reality games in developing English for Medical Purposes reading skills among 464 students. The study aimed to compare learning using commercial augmented reality games with self-designed games within the flipped classroom model, through an integrated quantitative and qualitative analysis. The results showed that the classes using self-designed games were superior in improving academic and field reading, with students exhibiting positive perceptions of practical, team-based learning in the flipped classroom environment. Khodabandeh's (2023) study aimed to examine the effectiveness of augmented reality (AR)-based gamification in developing English as a Foreign Language (EFL) learners' request and direction-giving skills within flipped and blended learning contexts. The study compared the performance of three groups (flipped, blended, and control) of 60 students over eight learning sessions. The results showed that the flipped and blended groups outperformed the control group in a post-test, highlighting the impact of combining AR gamification with flipped classroom methodology in enhancing language learning in both digital and face-to-face environments. Lu et al.'s (2021) study aimed to present the experience of developing and implementing an AR application for teaching an undergraduate chemistry course at City University of Hong Kong. The goal was to raise awareness, connect chemistry concepts to students' daily lives, and enhance their engagement in learning. The study aimed to evaluate

the application's effectiveness in improving understanding and interest in chemistry topics through a pilot questionnaire. The results showed positive responses from students regarding the application's impact on increasing awareness, understanding, and engagement in learning, confirming the role of augmented reality as an effective tool for addressing low motivation in chemistry education.

Learning Engagement

The current research is based on the premise that engagement in learning is a fundamental element of effective learning, reflecting the learner's interaction, interest, and positive participation in educational situations. The flipped classroom model, supported by augmented reality, contributes to enhancing this engagement by combining pre-lesson self-learning with immersive, interactive activities during the lesson. This provides learners with broader opportunities for experimentation, discussion, and application of concepts. Consequently, this integration strengthens behavioral, cognitive, and emotional engagement levels, transforming the learner from a passive recipient to an active participant in knowledge construction.

Engagement in learning is defined as the intensity of feelings that motivate a learner to initiate and continue learning activities (Skinner & Belmont, 1993). It is also viewed as a psychological process manifested in attention, interest, and the investment of effort and abilities during various learning situations (Klem & Connell, 2004). Engagement expresses active and energetic participation directed towards accomplishing academic tasks, coupled with high levels of attention, interest, and enjoyment during learning (Manwaring et al., 2017).

Engagement typically consists of three main components. The first is behavioral engagement, which is manifested in active participation in classroom activities and the completion of educational tasks (Al-Obaydi et al., 2023; Liu et al., 2023). Cognitive engagement refers to the learner's efforts in employing self-regulated learning strategies and striving for deep understanding (Tang & Hew, 2022; Yang & Ghislandi, 2024). Emotional engagement, on the other hand, is related to positive feelings, attitudes, and perceptions toward learning and the educational institution (Chhetri & Baniya, 2022; Yang et al., 2021).

Engagement in learning is a key factor in academic success, as it helps predict learners' learning processes and achievement. Furthermore, it provides evidence of a learner's potential for success in practical life, their ability to adapt to challenges, and their capacity to solve problems scientifically (Skinner et al., 2008). Learners who are motivated to engage in learning tasks have the opportunity to benefit more from the academic content presented in educational environments, participate in classroom activities, and receive greater support from their peers. In light of these factors, the achievement of students engaged in learning is higher than that of students who are not engaged in the learning process (Baker et al., 2008).

The researcher believes that the flipped classroom model, supported by augmented reality, represents a promising educational approach toward achieving deeper and more sustainable engagement in learning. It enables learners to integrate prior self-directed learning with an immersive, interactive classroom experience. This model contributes to empowering the learner as an active participant in knowledge construction through a stimulating

learning environment that supports exploration, discussion, and practical application. Accordingly, the researcher anticipates that implementing this model will lead to increased levels of behavioral, cognitive, and emotional engagement, and enhance intrinsic motivation for learning, positively impacting the quality of educational outcomes and university learning experiences in light of the demands of digital transformation.

Methodology

Approach

The current research adopted a quasi-experimental approach as the most suitable method for studying the causal relationship between the synergy of augmented reality and flipped classroom structures on learning engagement among higher education students. This approach allows for examining the impact of the independent variables (augmented reality and flipped classrooms) on the dependent variable (learning engagement) within controlled learning environments designed to demonstrate the effect of the independent variable on the dependent variable. The research also employed a descriptive-analytical approach during the study and design phases to analyze the characteristics of augmented reality and flipped classroom structures, and to identify indicators of learning engagement and its behavioral, cognitive, and affective dimensions, thus paving the way for the development of the proposed experimental model.

Experimental Design

The experimental design with two experimental and control groups was used, where the first experimental group is the group that will study using flipped classrooms and augmented reality, while the control group is the group that uses flipped classrooms but without augmented reality. Figure 1 illustrates the experimental design of the research.

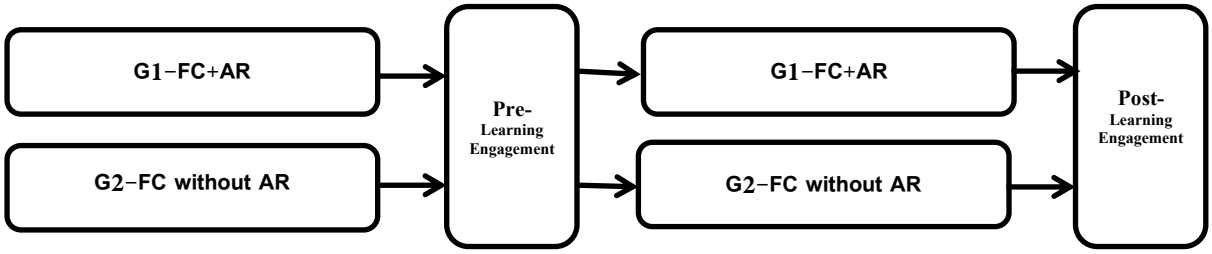

Figure 1. Experimental Design of Research Variables

The quasi-experimental approach was used in the current research to uncover the relationship between the variables. The independent variable was flipped classrooms supported by augmented reality, while the dependent variable was engagement in learning.

Sample

The research sample consisted of 60 preparatory year students at Jeddah University, randomly selected from those

enrolled in the Learning Resources course, an elective course at the university. The sample was divided into two equivalent groups:

- The experimental group, comprising 30 students, studied within a learning environment based on the synergy of augmented reality with a flipped classroom structure. Interactive digital content was employed, integrating self-directed learning before class with practical activities enhanced by virtual elements during class.
- The control group, also comprising 30 students, studied within a traditional electronic environment that did not rely on augmented reality but used the flipped classroom model. Typical classroom activities were conducted, and students received video content before class.

The distribution of participants was designed to ensure parity in cumulative grade point average and overall academic achievement, guaranteeing that any potential differences in results could be attributed to the synergy between augmented reality and the flipped classroom model, and not to individual or other academic factors.

Engagement Scale

This research developed a Learning Engagement Scale to measure the impact of integrating augmented reality with flipped classroom structures on the engagement of students enrolled in elective courses at Jeddah University. The scale aims to identify the degree of student engagement resulting from exposure to a learning environment based on the integration of augmented reality and flipped classrooms, by observing their behavioral, cognitive, and emotional engagement. Based on a review of relevant literature and studies on learning engagement scales (Assefa et al., 2025; Fredricks et al., 2005; Friedrich, 2010; Manwaring et al., 2017; Wang & Xue, 2024; Williams, 2014), and interviews with a group of experts, the scale's three dimensions were defined:

- *Behavioral Engagement:* Measures the extent of student participation in various learning activities and the level of interaction in the learning environment. It consists of 12 items.
- *Cognitive Engagement:* Measures students' efforts to understand the content and apply self-regulated thinking strategies. It consists of 12 items.
- *Affective Engagement:* Measures positive attitudes, feelings, and perceptions toward learning in the flipped classroom environment supported by augmented reality. It consists of 12 items.

Student responses are rated using a five-point Likert scale (1 to 5), where a higher score reflects a higher level of engagement. The total score on the scale ranges from 36 to 180, with a neutral score of 108. The scale's validity was verified by presenting it to a panel of expert reviewers, who commented on the need to link the scale items to engagement practices in augmented reality-enhanced learning environments and flipped classrooms. Correlation coefficients between the items and their dimensions were then calculated, ranging from 0.77 to 0.82, indicating good construct validity. The scale's reliability was also verified using the test-retest method, yielding reliability coefficients of 0.86 for behavioral, 0.82 for cognitive, and 0.81 for affective, with an overall mean of 0.83, indicating a high degree of internal consistency. The average administration time was 20 minutes, and the final version of the scale comprised 30 items equally distributed across the three dimensions. Therefore, this scale is a valid and reliable tool for measuring the level of engagement in learning resulting from the synergy between

augmented reality and flipped classroom structures among higher education students.

Procedures

This research was conducted according to a systematic plan aimed at studying the impact of augmented reality (AR) integration with the flipped classroom model on learning engagement among higher education students at Jeddah University, within the Learning Resources course. The procedures included several main stages, as follows:

First: Preparation Stage

1. Analysis of Educational Content: The content of the Learning Resources course was analyzed to identify concepts and skills that can be employed within a learning environment based on flipped classrooms and augmented reality, with a focus on concepts that require practical understanding or visual interaction, such as utilizing learning resources in self-directed learning processes during university studies.

2. Design of the Digital Learning Environment:

- The Edpuzzle platform was used to present pre-lesson content through interactive educational videos integrated with short questions and immediate responses, designed to stimulate thinking and activate prior knowledge before class.
- The Zappar application was used to design augmented reality activities within the classroom, providing an immersive learning environment that allows students to interact with 3D elements, images, and digital models that simulate the components of real-world learning resources.

3. Preparing the measurement tools: The Learning Engagement Scale was prepared in its final form, including three dimensions (behavioral, cognitive, and emotional), to verify the level of student engagement in learning in light of the application of the proposed model.

Second: Implementation Phase

1. Sample Selection and Division: The research sample was randomly selected from (60) students from Jeddah University and divided into two groups equivalent in terms of their level of engagement in learning:

- First Experimental Group (30 students): This group studied using a synergistic model combining augmented reality and flipped classrooms. They interacted with Edpuzzle content before class and then completed classroom activities using the Zappar application.
- Second Experimental Group (30 students): This group studied the same content using a traditional flipped classroom approach without the use of augmented reality.

2. Implementation of Learning Phases:

- Pre-Class Phase: Students in the experimental group were directed to watch educational videos using

Edpuzzle and answer the embedded questions to activate prior knowledge.

• Class Phase: Students used the Zappar application to complete augmented reality activities that included exploring digital models of learning resources and discussing their functions within collaborative groups.

• Post-Class Phase: Reflective and self-assessment activities were conducted via the learning platform to enhance comprehension and develop critical thinking skills.

3. Experiment Control: Equivalence factors were ensured between the two groups in terms of age, academic level, and specialization to guarantee that any differences were attributable to the effect of the proposed model and not to external factors. Participating faculty members were also trained on the use of the Edpuzzle and Zappar platforms to ensure standardization of procedures.

Third: Measurement and Analysis Phase

1. Applying the Measurement Tools: Following the completion of the experiment, the Learning Engagement Scale was administered to both experimental groups to measure the three dimensions of engagement (behavioral, cognitive, and affective) and to identify differences resulting from the application of the model based on the synergy of augmented reality and flipped classrooms.

2. Statistical Processing: The data were entered and analyzed using the SPSS statistical software. An independent samples t-test was used to verify the statistical significance of the differences between the means of the two groups. Effect size values (Eta-squared) were also calculated to determine the extent of the proposed model's impact on the level of learning engagement.

3. Interpretation and Analysis: The results were interpreted in light of the theoretical framework and previous studies that addressed the role of augmented reality and flipped classrooms in enhancing interaction and immersion in learning. The implications of the proposed model for developing higher education environments were also discussed.

Results and Discussion

To answer the main research question and to verify the hypothesis of comparing the first experimental group, which used the flipped classroom environment supported by augmented reality, and the second experimental group, which used the same flipped classrooms without augmented reality synergy, the t-test was used to identify the significance of the differences between the experimental and control groups. Table 1 shows the results of the t-test for the members of the two research groups.

By extrapolating the data from Table 1, it is clear that the experimental group, which used flipped classrooms enhanced with augmented reality, outperformed the second experimental group, which used flipped classrooms without augmented reality.

Table 1. Mean, Standard Deviation, and t-value for the Levels of Engagement in Learning of the Two Experimental Groups

Group	N	Mean	SD	t	df	sig	η^2
G1-FC+AR	30	174.16	3.17	54.99	58	0.000	0.98
G2-FC without AR	30	133.77	2.47				

Figure 2 illustrates the comparison between the experimental and control groups in terms of their average total engagement scores in learning.

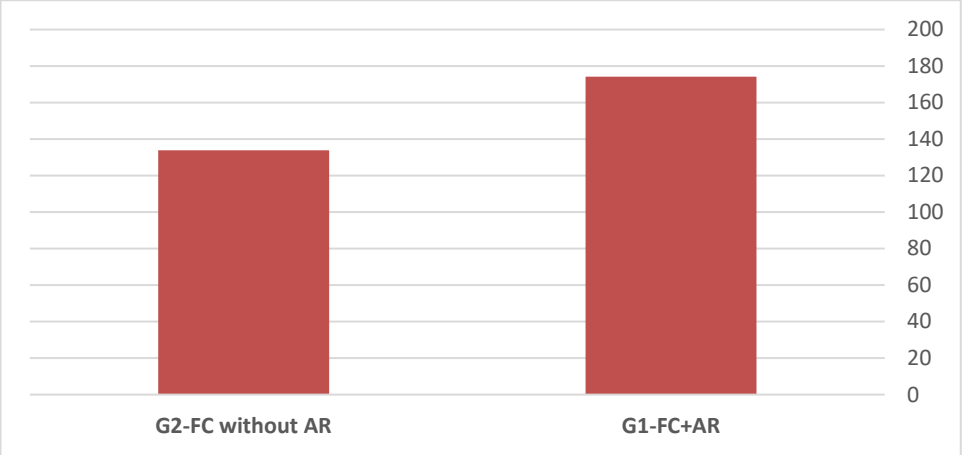

Figure 2. Difference between the Experimental and Control Groups for Engagement in Learning

Consequently, the results of this study, which examined the impact of augmented reality combined with the flipped classroom structure on the overall learning experience of higher education students, indicate that this synergy is one of the most effective interactions in enhancing learners at all three levels: behavioral, cognitive, and affective. The first experimental group, which successfully integrated augmented reality with flipped classrooms, outperformed the second experimental group, which only implemented flipped classrooms without augmented reality. This reflects the constructive role of combining the two technologies in creating a more stimulating and interactive learning environment.

The current finding, demonstrating the effectiveness of a blended learning environment based on augmented reality synergy with the flipped classroom structure in enhancing learning engagement, can be attributed to the nature of the educational activities that combined self-directed pre-class interaction via the Edpuzzle platform with an immersive classroom experience through the Zappar application. This environment provided students with a dynamic learning experience that fostered curiosity and participation. Interactive pre-class videos helped activate prior knowledge and stimulate interest in learning topics, while augmented reality within the classroom enabled students to interact with the content in a way that made educational concepts clearer and more realistic.

The integrated learning environment, combining flipped classroom and augmented reality technologies, provided an extended learning experience, making students more immersed, attentive, and engaged in educational activities. Zappar's self-exploration and collaborative nature also fostered a sense of control and independence, further

increasing student engagement during learning.

This integrated experience, which combined pre-learning using video platforms with immersive classroom interaction using augmented reality, helped learners organize their own learning and employ deeper cognitive strategies. This increased their awareness of how to apply concepts and connect them to real-world contexts, and boosted their confidence and enthusiasm for the course. Therefore, the synergy between augmented reality and flipped classrooms created a stimulating learning environment that supported behavioral, cognitive, and emotional engagement simultaneously, making the learning process more meaningful, enjoyable, and sustainable.

This finding aligns with the results of Antoniou et al. (2024), which demonstrated that integrating augmented reality into the flipped classroom model led to a significant improvement in cognitive achievement and increased motivation levels. This was achieved by providing students with an experiential and hands-on learning environment, a goal also realized in the current study through Zappar's interactive classroom activities. Furthermore, these results are consistent with those of Campos-Mesa et al. (2022), which showed that using augmented reality videos in flipped learning enhances motivation and attention compared to traditional media, thus explaining the observed increase in behavioral and emotional engagement levels in that study.

In the same vein, the current results support the findings of Ferrer-Torregrosa et al. (2016), which demonstrated the superiority of the augmented reality group over the other groups in comprehension and metacognitive understanding. This aligns with the higher cognitive engagement indicators observed in the first experimental group. Furthermore, these results are consistent with Khodabandeh's (2025) study, which confirmed that integrating augmented reality with flipped classrooms contributes to improved vocabulary learning and long-term retention. This can be explained by the enhanced self-learning and active engagement strategies facilitated by the current study model.

The results are also consistent with the study by Khazaie and Ebadi (2025), who indicated that augmented reality-based game-based learning activities within flipped classrooms lead to improved academic performance and an appreciation of the value of collaborative work. This was clearly reflected in the increased behavioral engagement of students in the first experimental group. The results of the study by Khodabandeh (2023) confirm that integrating augmented reality with flipped learning contributes to improved performance in language tasks and attitudes toward learning. Meanwhile, the study by Lu et al. (2021) supported the importance of augmented reality in raising awareness and connecting content to real life, thus enhancing emotional engagement with the learning material. This is the same finding revealed by the current study in terms of increased levels of emotional engagement. The current result is also consistent with the results of studies that have shown the role of digital technologies in enhancing interactions within the structure of classroom activities and improving many academic and psychological variables (Alrashedi et al., 2024a, 2024b; Ibrahim et al., 2024; Najmi et al., 2024; Zohdi et al., 2024). This result is also consistent with studies that have shown the effectiveness of both flipped classroom techniques (Akçayır & Akçayır, 2018; Chen Hsieh et al., 2017; Chen et al., 2018; Gupta et al., 2025; Morgan et al., 2015) and augmented reality (Buchner et al., 2022; Crogman et al., 2025; Gonnermann-Müller & Krüger, 2025; Jiang et al., 2025; Lampropoulos, 2025) in positively influencing learning outcomes.

Based on the above, the results show that the synergy between augmented reality and flipped classrooms not only increases engagement rates but also deepens learning and enriches the educational experience by integrating prior self-directed learning with immersive, hands-on classroom interaction. Therefore, these findings clearly support modern trends in higher education that emphasize the importance of integrating digital technologies with constructivist learning models as an effective approach to fostering deep and sustained learner engagement and achieving more interactive and relevant learning.

Limitations

In light of the findings of the current study on the synergy between augmented reality and flipped classroom structures and their impact on learning engagement among higher education students, it is important to note several research limitations that should be considered when interpreting the results. The experiment was limited to a small sample of students at Jeddah University enrolled in an elective course, which may limit the generalizability of the results to other academic groups with different characteristics. Furthermore, the study's duration was relatively short, which did not allow for monitoring the long-term impact of the synergy between augmented reality and flipped classrooms. Additionally, the study relied on self-assessment tools to measure learning engagement, which may be influenced by students' personal or social factors. Moreover, the study used two specific platforms, Edpuzzle and Zappar, and the results may differ if other digital tools with different technical specifications or levels of interactivity were used. Based on these limitations, the researcher recommends future research employing longitudinal designs to study the extended impact of the proposed model, using broader and more diverse samples from multiple disciplines and academic institutions, and utilizing objective measurement tools such as tracking learning behavior and analyzing digital interaction data. It is also suggested to explore the synergistic effect of augmented reality and flipped classrooms on other variables such as academic achievement, creative thinking, and motivation, thereby contributing to a deeper theoretical and applied framework for integrating educational technologies in higher education.

Conclusions

In light of the findings of the study examining the synergy between augmented reality (AR) and flipped classroom structures and their impact on learning engagement among higher education students, the research concluded that the integrated approach of AR and flipped classrooms represents an effective educational model for enhancing learning engagement across its behavioral, cognitive, and affective dimensions. The analysis revealed the superiority of the first experimental group, which studied using the AR-flipped classroom model, over the second experimental group, which relied solely on flipped classrooms without AR. This superiority is attributed to AR's ability to create an immersive and interactive learning environment within the classroom, providing students with broader opportunities for experimentation, discovery, and active participation, thus contributing to increased motivation and engagement in learning.

These findings confirm that integrating augmented reality with flipped classrooms not only enhances classroom interaction but also contributes to reshaping learners' roles toward greater independence and initiative, while

strengthening their emotional and cognitive engagement with the educational content. Accordingly, the study recommends adopting this model in university settings to develop deeper and more sustainable learning experiences and expanding its application across diverse courses to measure its impact on other educational variables such as academic performance and motivation. These results also provide practical evidence of the importance of investing in interactive educational technologies within the digital transformation plans of higher education institutions, supporting their shift toward student-centered learning.

Statements and Declarations

Supplementary Materials: "Not applicable."

Funding: "Not applicable."

Data Availability: "Not applicable."

Ethics Approval: All methods were performed in accordance with the study protocol and ethical guidelines and regulations.

Informed Consent: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The author declares no conflicts of interest.

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