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Learning 3D Computer-Aided Design on Immersive Platforms of Augmented and Virtual Reality

Chenxin Wu, Mengjie Huang, Rui Yang, Zhaoyu Xu, Wenxin Sun, and Liu Wang

Abstract—**In an era of rapidly evolving educational paradigms, the field of education is challenged by participation and the integration of innovative technologies. This study, therefore, introduces a novel learning platform for 3D Computer-Aided Design education, integrating Augmented Reality (AR) and Virtual Reality (VR) to enhance traditional educational methods and perhaps provide new sights for the direction of practice. It proposes three key features: Campus Exploration, 3D Modeling Instruction, and Modeling Rewards, each tailored to different phases of the learning process. The platform aims to improve learner motivation, user experience, and engagement through immersive technologies. A user study involving twenty participants compared the subjective experience of AR and VR interfaces against traditional teaching methods. The findings indicate that immersive platforms, especially AR, significantly enhance learning experiences compared to conventional methods. AR's integration with the real environment and its user-friendly nature, coupled with the portability of handheld devices, contribute to its superiority over VR in educational settings. This study underscores the potential of AR in 3D modeling education, suggesting that its incorporation into educational frameworks can profoundly impact learning outcomes. The research highlights the need for innovative educational models that incorporate immersive technologies to foster a more engaging and effective learning environment.**

Index Terms—**learning, 3D modeling, augmented reality, virtual reality, computer-aided design**

I. Introduction

In the landscape of traditional educational methodologies, educators frequently gravitate towards purpose-driven strategies, often culminating in an over-standardization of teaching methods. This tendency towards uniformity can inadvertently dampen student enthusiasm and impinge upon the efficacy of conventional pedagogical approaches [1]. Concurrently, the burgeoning trend of assisted learning concepts [2] has spurred educators to explore the integration of assistive tools. These tools aim to invigorate student engagement and enhance the learning experience, thus spotlighting the necessity for more innovative educational models [3]-[5]. Within traditional learning environments for 3D Modeling in Computer-Aided Design (CAD), the reliance on theoretical knowledge and case demonstrations is prevalent, aiding beginners to rapidly immerse in the educational process. However, the escalating influence of immersive technologies, such as augmented reality (AR) and virtual reality (VR), fueled by their growing accessibility and prevalence, is reshaping educational paradigms [6]. Notably, AR aligns with situated learning theory [7], while VR resonates with the constructivist learning approach [8]. Each, though distinct in its emphasis, is poised to offer enriched learning experiences [7][8]. Especially in the education context of CAD, as AR and VR also utilize the techniques of 3D modeling for developing 3D models and environments, they possess a strong link with CAD and can serve as an immersive assistant in its learning. Despite their apparent potential, the pragmatic application of these technologies in educational settings requires further exploration.

Addressing this gap, this study introduces an assisted learning platform for 3D modeling underpinned by immersive technologies and characterized by three principal features that draw on the concept of gamified learning: Campus Exploration, 3D Modeling Instruction, and Modeling Rewards. This innovative platform integrates two pivotal immersive technologies, AR and VR, tailoring their application across the three critical phases of the modeling learning process in CAD: preparatory, active, and concluding phases. This approach is designed to yield substantial benefits for learners, particularly in enhancing user motivation, experience, and other subjective dimensions. Through conducting comprehensive user research, this study endeavors to ascertain the interactive assistance provided by these immersive technologies in the learning process. Additionally, this study elucidates the subjective variances between AR and VR when integrated within traditional educational frameworks, thereby offering a nuanced understanding of their respective impacts on the educational experience. This exploration is pivotal in charting new trajectories in educational technology and pedagogy, particularly in the realm of 3D CAD. This article contributes significantly to the field in several ways:

- This study presents an original assisted learning platform for 3D CAD that synergistically combines AR and VR technologies, providing a novel approach to modeling education.
- This study offers empirical insights into the comparative effectiveness of immersive technologies in enhancing the learning process, bridging a critical research gap in the

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application of immersive technologies in education.

- This study highlights the subjective differences between immersive technologies and traditional teaching methods, offering valuable perspectives for educators and policymakers in curriculum development.

II. Literature Review

A. Augmented Reality in Learning

AR is regarded as a revolutionary technique, that seamlessly integrates virtual content with the physical world, offering learners a unique spatial experience. This fusion has profound implications in educational spheres, where AR has risen as a formidable tool [9][10]. Studies have delved into the theoretical foundations of AR in education, examining constructivist learning theories and AR's potential [11]. Particularly in elementary education, AR has demonstrated its ability to enhance learning, especially in comprehending abstract scientific concepts. Initial research suggests AR's interactive nature makes complex topics more accessible and intriguing for young students [12]. Beyond primary education, AR's role in tertiary learning environments has been extensively examined. Studies underscore its efficacy in enriching academic experiences across disciplines [13]. AR provides immersive and interactive environments that help deepen students' comprehension and retention of information. Additionally, AR's impact in special education is gaining focus; its customization potential can significantly improve learning outcomes in specialized educational settings [14].

Despite these advantages, integrating AR into education faces challenges. Developing AR content and ensuring a high-quality user experience are substantial obstacles [15]. The demand for AR technology tailored for individualized learning, along with the need to balance complex and general subject matter, presents additional difficulties. These challenges are not solely technical but also pedagogical, necessitating a delicate balance between AR technological advancements and educational efficacy [16]. In sum, while AR offers transformative potential in educational contexts, its successful adoption hinges on overcoming these prevalent challenges [17]. Addressing these issues is critical for AR to revolutionize the educational landscape, making learning more immersive, accessible, and effective [15] [17].

B. Virtual Reality in Learning

VR technology has markedly revolutionized the interaction between users and digital content. With the utilization of controllers and head-mounted displays, VR offers an immersive experience, enabling profound engagement with virtual environments [18] [19]. This advancement has notably influenced the education sector, bolstering student engagement and fostering innovative thinking [20]. The introduction of VR as an immersive educational tool has sparked significant academic discourse, exploring its varied effects across different educational levels and fields. In educational contexts, VR's application is distinguished by its capacity to create dynamic and interactive learning spaces. These environments are designed to captivate students' attention and stimulate their creativity, thereby enhancing the effectiveness and engagement of learning processes [21]. Particularly, VR's ability to replicate intricate real-world scenarios provides a hands-on learning approach, improving comprehension, information retention, and fostering active learning and critical thinking skills [22]. However, the incorporation of VR in education is not without challenges. Issues such as high costs, the need for specialized equipment, and the risk of motion sickness in some users present notable obstacles [23]. Furthermore, a lack of high-quality, VR-specific educational content hinders the technology's educational potential [24].

Empirical studies, though, have demonstrated VR's positive influence on learning outcomes. Research indicates that VR can surpass traditional teaching methods by enhancing student performance, increasing engagement, and deepening emotional involvement [25]. Its immersive and interactive nature makes abstract and complex concepts more tangible and comprehensible, thus improving learning experiences [26]. An essential aspect of VR's educational discourse includes its integration into pedagogy and curriculum adaptation. It's crucial to address how VR supplements traditional teaching methods and the training educators require to efficiently implement VR technology in classrooms [27].

C. The Comparison between AR and VR

Immersive technologies, notably AR and VR, have become pivotal in various fields such as healthcare, entertainment, and education, gaining significant traction in modern society [28]-[30]. Numerous studies have focused on comparing AR and VR in different application scenarios, revealing varied outcomes. In education, a study employing the ARCS model for motivational design compared the effects of websites, AR, and VR on learning motivation [31]; this research found that VR excelled in promoting attention, relevance, and confidence, whereas AR was superior in terms of learner satisfaction. Despite these findings, there remains a research gap in the detailed comparison of AR and VR within the educational context [32]. In other domains, the distinction between AR and VR has been a subject of interest. For instance, one study explored the differences in agoraphobic environments and showed that both AR and VR can induce anxiety or fear at the right time in virtual environments, but there was no statistical difference [33]. In a study involving children tasked with object counting, no major difference in objective outcomes was found between AR and VR, though AR was more popular [34]. The healthcare sector has also seen comparisons between these technologies. Besides, VR's advanced visualization capabilities have been found more favorable among medical professionals compared to AR, suggesting a preference for VR in certain professional applications [35].

Overall, AR and VR can't be shown to be overwhelmingly superior under any circumstances. The efficacy of these technologies is highly context-dependent and varies with each specific use case. This situation emphasizes the importance of a detailed comprehension of the distinct advantages and limitations of immersive techniques, ensuring their application is tailored to fit the unique needs and circumstances of each scenario [36]. Recognizing and leveraging the unique qualities and capabilities of each technology is essential, rather than relying on a one-size-fits-all approach, to optimize their impact and utility in a variety of environments [37].

III. Framework Design

Traditional 3D modeling education, focused on foundational theories and manual practices, has effectively met learners' needs through hands-on operations and experiential learning [38]. However, technological advancements are reshaping this field, with digital modeling and CAD emerging as significant forces. This shift reflects a growing interest among learners in using emerging technologies for skill development in 3D modeling. Immersive technologies have evolved into powerful educational tools, offering significant contributions across various academic fields [39]. Decreasing costs and increasing accessibility have led to their experimental use in education [39]. This paper introduces a novel learning platform tailored for beginners in 3D modeling, integrating immersive technologies such as AR and VR. Centered around virtual campus environments, it aims to bridge the gap between conventional modeling education and the evolving demands of modern learning environments. These tools are instrumental in providing a comprehensive understanding of modeling techniques and enhancing learner enthusiasm.

A. Framework Features

This pedagogical framework for 3D modeling education follows a sequential structure: a preparatory phase before learning, an active learning phase, and a concluding phase with rewards. It integrates three main components: Campus Tour, 3D Modeling Instruction, and Modeling Rewards. Designed to progressively build interest and motivation, this gamified approach enhances understanding of spatial relationships in 3D models. Incorporating immersive technologies, it aims to improve learners' perceptual and interactive experiences, potentially enriching the learning environment and positively impacting educational outcomes.

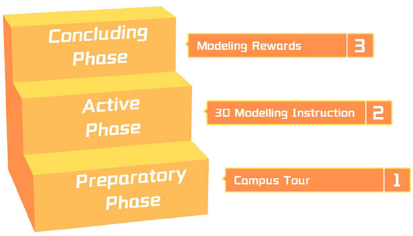

Fig. 1. Framework features

Campus Tour: In the proposed learning platform, the “Campus Tour” feature forms a foundational component, acting as a critical gateway to the learning platform. This initial stage is designed to captivate learners' curiosity and bolster their motivation, setting a robust foundation for the subsequent stages of the learning process. The campus landscape of the learner's university, meticulously reimagined and reconstructed in digital form, is presented as a series of intricate 3D models within virtual environments (Fig. 2). This digital representation is not merely a static replication; it is enriched with interactive and functional elements, integrating immersive technologies to create a multifaceted virtual campus experience. Before embarking on their educational journey of 3D modeling, learners are invited to immerse themselves in this virtual campus. Here, they are not mere spectators but active participants, exploring the intricacies of the campus through the corresponding system. One of the most notable features of this tour is the opportunity to observe and understand the modeling history of various campus structures. This exposure to the evolution and techniques involved in 3D modeling provides a context-rich pre-learning experience, laying an attractive groundwork for their subsequent educational endeavors. In the immersive settings, learners navigate the virtual campus using head-mounted devices (HMDs) within the VR interface, offering a fully immersive experience. In contrast, the AR interface is accessed through handheld devices, overlaying digital information onto the physical world, thereby providing a different but equally enriching experience. This innovative mode of campus touring extends beyond mere novelty; it serves as a powerful assistive tool for learning 3D modeling. By allowing learners to traverse the historical timeline of model creation of campus structures, it fosters an initial and intuitive understanding of 3D modeling process. This experiential learning approach is pivotal in stimulating learners' interest and reinforcing their motivation. It offers a preliminary glimpse into the world of 3D modeling, subtly introducing the thought processes and the outcomes behind it.

Furthermore, the Campus Tour embodies the principle of “learning by exploration”, a pedagogical approach that encourages learners to construct their understanding through active engagement. By navigating the virtual campus, learners are not just passive recipients of information but are actively constructing knowledge, an experience that resonates more profoundly than traditional didactic methods. This feature of the platform is instrumental in assisting conventional teaching paradigms, shifting the focus from teacher-centered instruction to learner-centered exploration.

3D Modeling Instruction: The “3D Modeling Instruction” component, integral to the learning platform, functions as an essential adjunct to traditional modeling education, enriching rather than replacing the established teaching methodologies. This module strategically blends with the conventional curriculum, offering an immersive and interactive dimension that enhances the overall learning experience. Central to this innovative approach is the virtual modeling workstation, where learners engage with 3D models in a dynamic virtual environment. This hands-on interaction facilitates a deep and practical understanding of the entire modeling process. The module is further enhanced by its unique guidance methods, including textual instructions and strategic highlights. These features offer real-time, tailored advice and tips, significantly augmenting the learning process. It’s crucial to recognize that this technology-enhanced instruction is intended to supplement, not supplant, traditional modeling teaching methods. The experiential learning provided by manual practices and face-to-face teaching remains indispensable. The 3D Modeling Instruction module aims to bridge the theoretical and practical aspects of modeling, thus providing a more holistic educational experience. This instructional method is designed to be universally applicable, catering to learners at various stages of the modeling process. From beginners grappling with basic shapes to more advanced learners dealing with complex structures, the system offers tailored support, making it an inclusive and adaptable learning tool. This feature is especially advantageous for beginners who require foundational guidance, ensuring that learners can progress at their own pace, building confidence and competence as they advance.

Moreover, the module's indirect benefits extend beyond skill acquisition in modeling. Engaging with 3D models in a virtual setting enhances learners' spatial awareness and visualization skills, which are broadly applicable and valuable. This approach also aligns with active learning and constructivist educational theories, promoting learners as active participants in their educational journey.

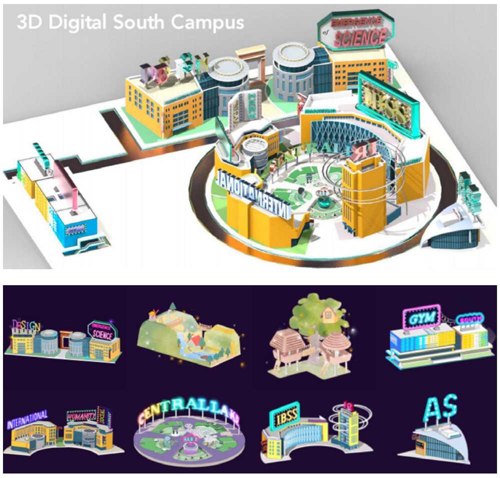

Fig. 2. Campus Model (top) and Modeling Reward (bottom)

Modeling Rewards: Within the innovative framework of the learning platform, the "Modeling Rewards" component encapsulates the concept of post-learning reward feedback, a fundamental aspect that aligns seamlessly with the principles of gamified learning. Gamification in education is a burgeoning field, recognized for its effectiveness in enhancing learner motivation and user experience through reward-based feedback mechanisms [41]. This approach significantly encourages learners to persevere and succeed in their subsequent learning tasks. Upon the successful completion of specific modeling tasks, students are awarded 2D graphic fragments corresponding to the model they have worked on (Fig. 2). These fragments are not merely symbolic achievements; they are designed to integrate into the learners' personalized settings, offering a tangible sense of progress and accomplishment. The accessibility of these rewards is a key feature, with the distribution of the 2D fragments designed to be easily retrievable through common electronic devices, ensuring that learners can view and appreciate their achievements with ease. In parallel to the reimagined 3D virtual campus, these 2D modeling fragments are artistically stylized. This stylistic enhancement is not just an aesthetic choice but a deliberate strategy to bolster learners' motivation to collect and cherish these rewards. The allure of these visually appealing fragments adds an additional layer of engagement to the learning process, making the acquisition of new skills both rewarding and enjoyable. The gamification aspect of the Modeling Rewards extends beyond mere engagement. It emerges as an effective pedagogical tool for instructors, enabling them to supplement traditional teaching methods and track course progress through a novel, interactive lens. This innovative integration of rewarding mechanisms into the educational framework represents a forward-thinking approach to reinforcing learning outcomes. It skillfully blends traditional educational techniques with modern, interactive elements, creating a dynamic, engaging, and more effective learning environment.

Besides, the introduction of such a rewarding system in the learning process is underpinned by psychological principles of reinforcement and motivation. When learners receive positive reinforcement in the form of these rewards, it not only acknowledges their efforts but also stimulates the intrinsic motivation to continue exploring and learning. This aspect is particularly effective in educational settings where sustaining student engagement and motivation can be challenging [41]. Modeling reward characteristics is a reflection of educational psychology.

In summary, the platform skillfully incorporates three key features, including Campus Tour, 3D Modeling Instruction, and Modeling Rewards, as supplementary aids to traditional teaching methods in modeling education. Campus Tour serves as an engaging pre-learning experience, utilizing AR and VR for explorative understanding. 3D Modeling Instruction feature enriches the learning process by providing interactive, virtual assistance in mastering modeling techniques. Finally, Modeling Rewards will motivate and acknowledge learners' progress. Together, these features enhance and aid traditional educational methods, providing an additional, interactive dimension to learning while complementing teaching and learning.

B. Development Tools

The development of this system is grounded in the use of Unity, a versatile platform renowned for its capacity to integrate diverse technologies such as AR, VR, Web, and User Interface (UI) techniques. In crafting the AR component, the system employs the Vuforia plugin, which facilitates desktop scanning and seamlessly integrates with the UI system and AR Foundation, culminating in a comprehensive AR experience. This functionality is optimized for deployment on handheld devices, like Mobile Phones (iPhone 15). In contrast, the VR dimension utilizes OpenXR, ensuring compatibility and high performance on HMDs like the Oculus Quest 2.

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IV. User Study

Upon the completion of the framework design integrating AR and VR platforms with traditional teaching methodologies for 3D modeling, a user study was initiated to examine the subjective experiences of participants utilizing these platforms. This study was conducted at the authors' university, and involved a diverse group of twenty students, encompassing undergraduates, graduates, and doctoral candidates, all of whom lacked prior experience in modeling. Prior to commencing the experiment, basic information regarding the user study was provided to each volunteer, and their informed consent was obtained through signed consent forms.

A. Experiment Setup

The experiment of this user study was setup to evaluate the integration of AR and VR platforms with traditional teaching methods in 3D modeling education. Utilizing two distinct platforms: the AR platform operated on handheld devices (iPhone 15 Pro) and the VR platform on HMDs (Oculus Quest 2). The study aimed to explore the learners' subjective responses with these immersive technologies alongside traditional instruction. Twenty participants, aged 20 to 30, were recruited for the study. To ensure a comprehensive evaluation, the study adopted a within-subject design, where participants were assigned to two groups, each experiencing both AR and VR platforms in conjunction with traditional teaching methods.

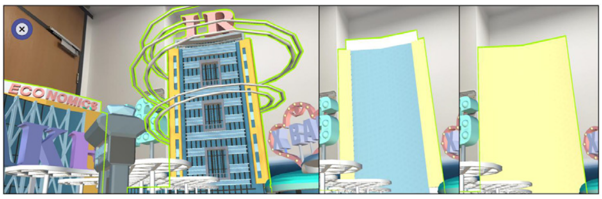

Fig. 3. Campus tour in AR settings

Fig. 4. Campus tour in VR settings

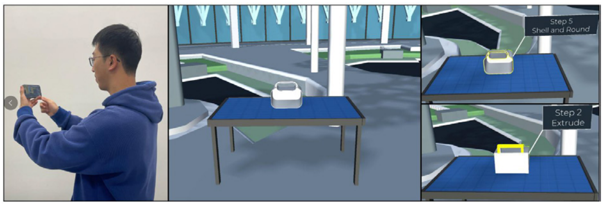

Fig. 5. 3D modeling instruction in AR settings

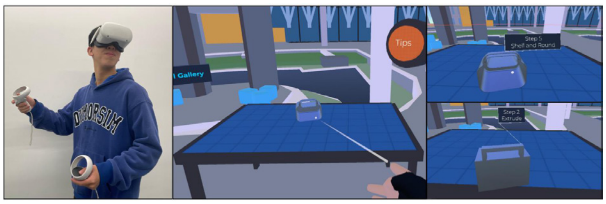

Fig. 4. 3D modeling instruction in VR settings

To ensure a thorough assessment, the study encompassed several phases in the experiment. In the first phase, participants were allowed to experience a full course of modeling instruction on a computer, including instructional videos and PowerPoint presentations. Immediately after, in the second phase, depending on the grouping, participants are guided to the virtual campus to visit the virtual campus and explore the modeling process of campus buildings in an AR or VR platforms (Fig. 3 and Fig. 4). This phase was crucial for them to familiarize themselves with the platform and future tasks. Subsequently, in the third phase, participants were allowed to conduct the 3D modeling guidance functions at the virtual modeling table in the AR or VR setup for the content told in the traditional course (Fig. 5 and Fig. 6), providing practical insights into the results of the platform. In turn, the content carried out in phases 2 and 3 will be repeated in phases 4 and 5 on another platform based on the group arrangement.

B. Measurements & Discussion

In this study, self-report evaluations were conducted at the end of the first, third and fifth phases of the experiment through Questionnaire A to compare traditional teaching methods with two immersive platforms, specifically focusing on four dimensions of subjective experience, as shown in Table I. The results, based on self-reported outcomes presented in Fig. 7, are discussed below in the context of each dimension.

TABLE I
QUESTIONNAIRE A

Overall experience	I feel it is easy to learn 3D modeling with this learning method.
	I feel it is interesting to learn 3D modeling with this learning method.
	I feel it is effective to learn 3D modeling with this learning method.
Confidence	I am confident to accomplish similar 3D modeling task after learning.
Motivation	I become more interested in 3D modeling task after learning.
Satisfaction	I am satisfied with this learning method.

1) Overall Experience: Figure 7(i) reveals that while there was no significant difference between the immersive platforms regarding overall experience, a marked contrast was noted between traditional teaching and both AR ($\chi^2=7.39$, $p=0.0065$) and VR ($\chi^2=4.95$, $p=0.0259$). Notably, the immersive platforms scored significantly higher than traditional teaching (M=0.6), with AR (M=1.97) slightly outperforming VR (M=1.73). This suggests that while both AR and VR enhance the learning experience compared to traditional methods, AR may offer a marginally more engaging overall experience.

2) Confidence: As depicted in Figure 7(ii), no significant differences were observed in confidence levels between traditional teaching and the immersive platforms, nor between AR and VR. However, the average scores indicate a trend where the AR platform scored the highest (M=2.15), followed by VR (M=1.65), and traditional teaching the lowest (M=1.15). This suggests that while not statistically significant, immersive platforms may instill a higher sense of confidence in learners compared to traditional methods.

3) Motivation: Significant disparities were identified in motivation levels, as shown in Figure 7(iii). A notable difference was observed between the immersive platforms ($\chi^2=8.09$, $p=0.0045$), and both AR ($\chi^2=19.78$, $p<0.0001$) and

VR ($\chi^2=7.28$, $p=0.007$) significantly outperformed traditional teaching. AR once again scored highest (M=2.6), followed by VR (M=1.55), and traditional teaching scored substantially lower (M=0.15). This indicates a clear motivational advantage for immersive platforms, particularly AR.

4) Satisfaction: Figure 7(iv) indicates no significant differences in satisfaction between AR and VR platforms. However, both AR ($\chi^2=8.41$, $p=0.0037$) and VR ($\chi^2=4.07$, $p=0.0435$) demonstrated significant improvements over traditional teaching. The overall satisfaction scores were notably higher for the immersive platforms than for traditional teaching (M=0.5), with AR (M=2.1) leading over VR (M=1.5). This suggests that while both platforms enhance satisfaction, AR might provide a slightly more satisfying experience.

The results indicate that while AR and VR platforms offer no significant differences in some aspects, they both significantly enhance the overall experience, motivation, and satisfaction of learners compared to traditional teaching methods. AR, in particular, seems to offer a slight edge over VR in these areas. This study underscores the potential of immersive technologies to augment traditional educational approaches, providing a more engaging, confidence-boosting, and satisfying learning environment.

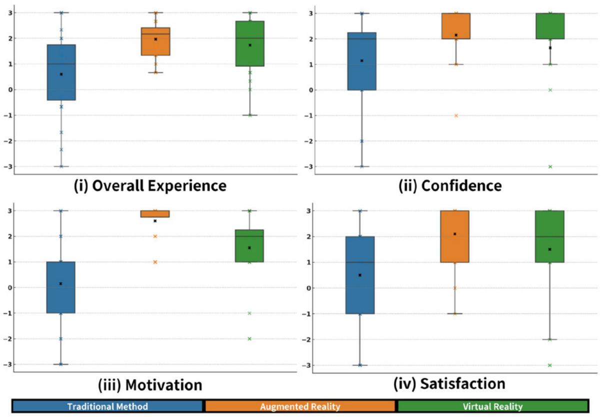

Fig. 5. Self report results of Questionnaire A

Additionally, after the third and fifth phases of the experiment, the performance of two critical features: learning motivation related to the Campus Tour and learning effectiveness associated with 3D Modeling Instruction, were scrutinized through self-reports with Questionnaire B (Table II). Participants were also required to fill in the User Experience Questionnaire (UEQ) and the System Usability Scale (SUS) after the third and fifth phases, with the aims to assess the user experience and the usability of the immersive platforms. The ensuing section delineates the results for each dimension, grounded in self-report outcomes displayed in Fig. 8.

TABLE II
QUESTIONNAIRE B

Campus Tour	A tour of the virtual campus sparked my interest in 3D modeling.
	Watching the modeling history of campus structures sparked my interest in 3D modeling.
Modeling Instruction	The virtual modeling instruction module helps me understand 3D modeling more easily.
	The virtual modeling instruction module helps me learn 3D modeling skills more efficiently.

5) Learning Motivation: Figure 8(i) reveals a notable disparity in learning motivation between the AR and VR platforms ($\chi^2=3.99$, $p=0.0458$). AR (M=2.075) exhibited a higher average motivation score compared to VR (M=1.625). This suggests that the AR version of the Campus Tour might be more effective in engaging and motivating learners.

6) Learning Effectiveness: As illustrated in Figure 8(ii), while there was no statistically significant difference in learning effectiveness between the AR and VR platforms, AR (M=2.125) consistently scored higher on average than VR (M=1.5). This trend indicates a possible preference or suitability of AR in enhancing the comprehension and application of 3D Modeling Instruction.

7) User Experience: Figure 8(iii) indicates a significant difference in user experience between the AR and VR platforms ($\chi^2=4.9$, $p=0.0269$), with AR (M=2.1063) notably outperforming VR (M=1.4375). This suggests that users found the AR interface or interaction more pleasant or intuitive, contributing to a more positive learning experience.

8) Usability: As depicted in Figure 8(iv), no significant difference was observed in the usability scores between AR and VR. However, AR (M=81.75) demonstrated a higher average usability score compared to VR (M=74). Although not statistically significant, this trend might indicate a slight preference or ease of use associated with the AR platform.

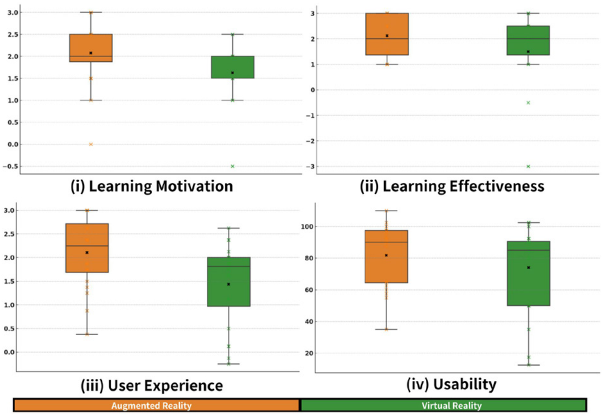

Fig. 6. Self report results of Questionnaire B, UEQ and SUS

This part of findings underscores the nuanced differences in learner engagement, effectiveness, user experience, and usability between the AR and VR platforms. While both platforms exhibit strengths, AR consistently scored higher across several metrics, suggesting it may offer a more compelling and user-friendly approach in certain contexts. These insights are invaluable for educators and developers seeking to optimize immersive technologies for enhanced educational outcomes.

In general, the analysis of self-reported outcomes across eight dimensions underscores the positive impact of immersive platforms on 3D modeling instruction. When compared to traditional teaching methods, AR and VR platforms often show superior performance, likely due to their more engaging and realistic experiences, coupled with enhanced spatial representation. Notably, AR consistently outperforms VR, potentially owing to its integration with the real environment, fostering improved spatial imagination critical for modeling. Additionally, the portability and familiarity of handheld AR devices over HMD VR systems offer greater convenience and practicality. These results indicate that while both AR and VR are effective for modeling education, AR's unique blend of real-world context and user-friendliness makes it particularly advantageous for enhancing learning experiences in modeling education.

V. Conclusion

This study, meticulously anchored in the three main features of the proposed framework, presents a compelling approach to integrating immersive technologies into modeling instruction. Embracing an educational lens, it becomes evident that immersive technologies like AR and VR significantly enhance learners' engagement through situational learning, providing access to content and experiences that transcend the limitations of traditional educational methods. These assistive platforms, particularly beneficial for novices, offer several trifold advantages, such as fueling learning motivation, enriching the user experience, and heightening the relevance of educational content. Further, the research delves into the subjective distinctions elicited by the use of immersive platforms in contrast to conventional teaching methods. The findings illuminate that immersive platforms complement and positively augment traditional teaching approaches. Notably, the study reveals a pronounced superiority of handheld AR environments over head-mounted VR settings in terms of overall effectiveness and user preference. This is likely due to AR's seamless blending of digital and real-world elements, fostering an enriched, more accessible learning experience. Consequently, this study posits that a greater emphasis should be placed on handheld AR when developing content for modeling instruction utilizing immersive technologies. Its demonstrated effectiveness, coupled with ease of use and practical applicability, makes it an ideal choice for enhancing modern educational practices in 3D modeling. This insight is pivotal for educators and content developers, highlighting the transformative potential of AR in reshaping and advancing the landscape of educational technology.

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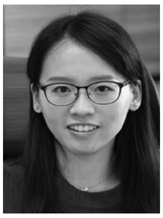

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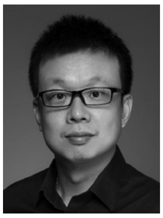

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