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Developing Virtual Reality-facilitated Artificial Intelligence-driven Instructor for English Grammar Acquisition

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Article

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Abstract

This study reports the experimental design and preliminary results of a virtual reality (VR)-based learning product on students' intrinsic motivation and English grammar acquisition. We developed a VR product equipped with artificial intelligence (AI) that serves as an instructor, called English Adventure, to facilitate an English grammar course. The course is guided by self-determination theory (SDT), which aims to enhance learner intrinsic motivation and learning engagement. Diverse instructional strategies (e.g., game elements and collaborative learning) were incorporated into VR scenarios to satisfy students' basic psychological needs of autonomy, competence, and relatedness. A mixed-methods approach was employed, combining quantitative data from pre- and post-tests with qualitative insights from individual semi-structured interviews with 20 postgraduate students. The research design underscores the integration of VR technology and AI interaction to address challenges in conventional grammar instruction. Our research findings indicate that the use of the VR-facilitated AI-driven instructor can significantly enhance students' grammatical mastery. However, the impact on their intrinsic motivation demonstrates a multidimensional variant contingent on many factors, such as students' profiles, course design, and instructor facilitation. Furthermore, our research suggests that the implementation of VR products in language education is hindered by technological limitations and individual differences, resulting in a contentious evaluation of their effectiveness. These findings position VR as a valuable supplement to traditional grammar education, provided technical and ergonomic challenges are addressed to optimize learner experiences.

Introduction

While learning English as a second language, Chinese learners often face significant challenges, whether in oral English or written English, especially in mastering the abstract grammatical structures. It is known that the Chinese language lacks functional equivalents to those found in the English language (Robertson, 2000). Grammar serves as the foundational framework for effective communication in English, and tenses are a core component of grammar (Debata, 2013). There are seven traditional forms of tenses in English, and the present perfect tense is included. It is a tense that locates a situation in the pre-present zone, emphasizing the relevance of the event extending from the past to the present, rather than being completely detached from the present (Declerck et al., 2006). Learners struggle to shift from Mandarin's focus on action completion to English's emphasis on ongoing relevance, often perceiving grammar as abstract rules disconnected from practical use. This difficulty reduces enthusiasm for learning, participation, and classroom interaction, hindering effective grammar acquisition (Gardner, 2020). Traditional teaching methods, which rely on rote memorization, fail to provide contextual support and real-time, personalized feedback from teachers, thereby exacerbating frustration for Chinese learners who depend on situational cues to grasp tense usage (Ellis, 2006; Norris & Ortega, 2000). Most teachers take more consideration of the learning outcomes rather than whether the students' basic psychological needs were satisfied during the learning process (Hwang & Chang, 2024).

The adoption of educational technologies has significantly transformed language education practices. For example, virtual reality (VR) offers a potential option by creating immersive, interactive environments that simulate real-world contexts for grammar practice (Parmaxi, 2023). VR technology has been proven effective in various language education scenarios, such as vocabulary learning and speaking simulation, but still lacks empirical evidence in grammar education (Parmaxi, 2023). Unlike traditional methods, VR technology used in the context of language education has been shown to provide learners with an immersive environment that mirrors real-life scenarios, enhancing motivation and comprehension (Huang et al., 2021; Lan, 2020). This, in turn, has been demonstrated to enhance the meaningful practice of contextual language use and the acquisition of grammatical forms (Lin & Lan, 2015). Additionally, with the rapid development of artificial intelligence (AI), its deep integration into language education is growing increasingly. The application of AI in language learning often manifests in the ability to provide highly personalized learning feedback (Authors, 2023), thereby accurately identifying learners' knowledge gaps and tailoring instruction to their individual learning needs and aptitudes. AI enables personalized feedback to clarify tense usage, which can be a supportive tool in the VR environment. Complementing VR, AI offers personalized feedback and adaptive learning pathways, supporting students' language learning (Luckin et al., 2016). A study demonstrates that an intelligent virtual reality (IVR) system, which combines AI and VR, can significantly enhance English competence (Hemminki-Reijonen et al., 2025).

Further, self-determination theory (SDT) identifies autonomy, competence, and relatedness as core drivers of intrinsic motivation (Ryan & Deci, 2000). When integrated with SDT, the combined potential of VR and AI becomes particularly promising. SDT-based VR designs have been shown to enhance motivation by satisfying the three basic psychological needs, leading to improved language uptake (Huang et al., 2019). The combination of AI, VR, and SDT can transform traditional and monotonous learning methods into immersive, personalized, and motivation-driven learning experiences. The AI-driven virtual characters and immersive VR environments can better simplify the complex concepts in English grammar learning, provide personalized feedback to assist learners in improving their weak areas, thereby enhancing the interactivity and motivation of language learning (Hemminki-Reijonen et al., 2025). SDT provides a theoretical framework for understanding the learning motivation underlying the usage of AI and VR in grammar educational scenarios (Zhai et al., 2024).

Although VR's potential to boost intrinsic motivation in language education is well-documented, its effectiveness in teaching specific grammar structures, particularly when combined with AI and SDT, remains underexplored for Chinese learners. To bridge this gap, our study investigates the impact of a VR-facilitated AI-driven instructor on Chinese learners' acquisition of the present perfect tense, addressing two research questions:

- To what extent does a VR-facilitated AI-driven instructor enhance learners' intrinsic motivation and cognitive mastery of the present perfect tense?
- What are the subjective experiences of learners with a VR-facilitated AI-driven instructor for grammar instruction?

Literature review

Technology enhanced grammar education

The integration of technology into grammar education has undergone significant evolution over the past few decades. Early developments focused on drill-and-practice software that reinforced rote memorization of grammatical rules, such as verb conjugations and sentence structures, often limited by the constraints of desktop computing (Bikowski, 2018). Technology-enhanced grammar instruction began using multimedia resources in the early 2000s. These resources, including interactive quizzes and online platforms, have improved accuracy in writing and speaking by providing immediate feedback (Celik, 2024; Marsaulina, 2020). This shift marked a pedagogical move toward constructivist approaches, where learners actively construct knowledge through interaction with digital environments rather than passively receiving information (Liu et al., 2023). Recent advancements have incorporated adaptive learning systems powered by data analytics, enabling personalized instruction that adjusts to individual proficiency levels and learning paces (Kaur et al., 2023). Studies have demonstrated that such technology-integrated methods yield modest to significant improvements in grammar mastery by fostering repeated exposure and error correction in authentic contexts (Celik & Kara, 2024). For instance, research on technology-enhanced environments for English as a second language (ESL) learners highlights enhanced retention and motivation when grammar lessons incorporate gamified elements and collaborative online tools (Almohideb, 2025; Hasumi & Chiu, 2024).

Among the diverse educational technologies, VR and AI have emerged as transformative tools in grammar education. VR facilitates grammar acquisition by simulating real-world scenarios in which learners can practice tense usage in dynamic and context-rich environments, thereby bridging the gap between theoretical knowledge and practical application (Lan, 2020; Lin & Lan, 2015). For example, studies on VR-based language immersion show improved vocabulary and grammatical accuracy through embodied cognition, where physical interactions in virtual spaces reinforce syntactic patterns (Piayura et al., 2025). Meanwhile, AI-driven tools, leveraging natural language processing (NLP), play a pivotal role by providing real-time, personalized feedback on grammatical errors, adaptive lesson sequencing, and even conversational simulations tailored to the present perfect tense (Authors, 2023; Stevens, 2025). A systematic review of 42 studies indicates that AI integration yields key affordances for English grammar proficiency, particularly in writing, through tools like Grammarly, which deliver statistically significant improvements in grammatical accuracy, emotional engagement, and self-efficacy, alongside enhancements in self-regulated learning and motivation compared to conventional methods (Crompton et al., 2024). The synergy of VR and AI is expected not only to mitigate common problems in grammar instruction but also to foster deeper linguistic competence through interactive and adaptive immersion (Ma, 2021).

SDT and grammar education

SDT, developed by Deci and Ryan, is a framework for understanding motivation, focusing on autonomy, competence, and relatedness as key needs for intrinsic motivation, well-being, and performance (Ryan & Deci, 2017). SDT distinguishes between intrinsic motivation, driven by personal interest and enjoyment, and extrinsic motivation, influenced by external rewards or pressures. It suggests that environments satisfying students' basic psychological needs can internalize extrinsic motivation, leading to sustained engagement (Ryan & Deci, 2000). Across language learning, SDT offers a framework for understanding how learners approach tasks, such as mastering verb tenses, within environments that cater to their psychological needs (Dörnyei & Ushioda, 2011).

The three basic psychological needs—autonomy, competence, and relatedness—are central to the application of SDT in grammar learning. Autonomy entails self-directed behavior aligned with personal interests, promoted by offering choices, reducing external control, and encouraging independent learning (McEown et al., 2014; Ryan & Deci, 2000). Allowing learners to choose grammar topics relevant to their goals satisfies their need for autonomy, increases intrinsic motivation, and enhances persistence (Eppendi & Laksana, 2025). Competence involves feeling capable and effective in one's actions, supported by appropriately challenging tasks, clear feedback, and opportunities to demonstrate skills (Deci & Ryan, 2008; Oga-Baldwin & Nakata, 2017). For instance, Hiromori (2009) found that competence satisfaction strongly predicted intrinsic motivation and language proficiency among Japanese EFL learners, particularly in tasks involving clause integration. While learning complex grammatical content, the competence need can be supported through structured exercises that progress from basic to complex forms, paired with constructive feedback that builds confidence and reinforces mastery. Relatedness refers to the need for meaningful connections and a sense of belonging, cultivated through supportive teacher-student interactions, peer collaboration, and community-building activities (Noels et al., 2019; Ryan & Deci, 2017). For instance, Yang et al. (2025) showed that social support from peers and teachers significantly predicts relatedness in self-directed e-learning, mediating enhanced motivation and engagement through online group discussions. In English grammar classrooms, the relatedness need can be fostered through group tasks, such as discussing the use of the present perfect tense or providing peer feedback on sentence structures.

Although SDT is well-established in educational psychology, its application to learning English grammar, which requires precise mastery of rules, is underexplored. Research in SLA often focuses on communicative skills, such as speaking or vocabulary, with limited attention to grammar-specific motivation (Dincer et al., 2012; Noels et al., 2000). Grammar education plays a crucial role in English learning, and tenses are a vital component. The present perfect tense is a grammatically simple yet semantically complex tense that involves linking past and present actions within specific contexts. This pedagogical approach has been shown to effectively stimulate learners' competence needs through progressive practice and immediate feedback, thereby reinforcing learners' sense of mastery and promoting the internalization of rules and sustained persistence (Ryan & Deci, 2017). Concurrently, it fosters both autonomy and relatedness needs. To illustrate this point, the opportunity for learners to select content for self-directed practice or to share their experiences through group discussions has been shown to foster a sense of belonging, thereby enhancing motivation and internalization. This

approach poses significant challenges to the comprehensive fulfilment of psychological needs within SLA environments (Noels et al., 2000).

Connecting VR, AI, SDT, and grammar education

VR offers a promising approach to language education by creating interactive, immersive environments that align with SDT's principles (Lan, 2020; Yudintseva, 2023). Based on the findings of Huang et al. (2019), the application of VR in English education can be powerfully framed through the lens of SDT. The immersive and interactive nature of VR environments primarily supports the psychological needs of autonomy and relatedness, which are crucial for motivating learners. By allowing students to freely explore virtual worlds and interact with digital content at their own pace, VR satisfies their need for autonomy, thereby enhancing intrinsic motivation and engagement. However, the need for competence may require careful course design, as the study suggests that merely providing a VR environment is insufficient (Huang et al., 2019). Effectively designed VR-facilitated English learning experiences should leverage their strengths in promoting autonomy and social connection while intentionally scaffolding activities to build learners' competence and confidence in language use (Hwang et al., 2024). Despite these affordances, VR also introduces risks such as physical discomfort, cognitive overload, and potential distractions that could erode attention and confidence, thereby undermining competence and relatedness. To mitigate these issues, the use of VR in education should consider additional elements, such as incorporating game elements to reduce anxiety and teacher mediation for effective integration. (Hua & Wang, 2023).

In AI-assisted language education, SDT-based methods enhance autonomy by allowing students to choose their own learning paths—for instance, secondary students selecting interest-aligned AI projects—which increases engagement for all genders and achievement levels (Xia et al., 2022). Competence can be bolstered through structured guidance and feedback, enabling students to master AI skills, while relatedness can be nurtured via supportive teacher interactions and peer collaboration, promoting inclusive learning environments (Li et al., 2025; Xia et al., 2022). In language learning, teachers play a crucial role in meeting these needs by designing personalized activities and offering emotional support, although AI may occasionally compromise autonomy due to rigid interactions (Li et al., 2025). Additionally, AI may generate inaccuracies, such as hallucinations, that erode trust and competence by providing misleading feedback or fabricated content, or enable misuse, including plagiarism, cheating, and over-reliance, thereby compromising academic integrity and skill development (Shaw, 2025; Zhai et al., 2024). These risks can be mitigated by implementing "human-in-the-loop" designs, where educators oversee and override AI decisions, and by establishing institutional policies for the ethical use of AI, including detection tools for plagiarism and guidelines for responsible integration to foster competence and relatedness (Orhani, 2025).

In summary, we identify a critical convergence of theoretical and contextual research gaps from previous literature. While SDT provides a compelling framework for motivation in SLA, its application remains notably underexplored in the specific domain of English grammar learning, particularly in the mastery of

complex tenses, such as the present perfect. Although VR theoretically supports SDT by offering choice (autonomy), immersive feedback (competence), and collaborative spaces (relatedness), research has primarily examined vocabulary and speaking—not grammar—so its value for grammar instruction remains speculative (Huang et al., 2019; Yan et al., 2024). As a transformative tool, AI intersects with these needs by enabling personalized learning experiences that can enhance autonomy, competence, and relatedness, yet its integration into grammar-focused education lacks robust investigation (Li et al., 2025; Xia et al., 2022). This oversight creates a substantial gap in our understanding of the motivational mechanisms and the subjective, experiential dimensions of acquiring grammar skills in immersive environments. The present study will investigate the extent to which VR enhances intrinsic motivation and cognitive mastery of the present perfect tense with the assistance of AI. Additionally, it will capture the rich, subjective experiences of learners in this context. By doing so, this research will provide empirical insights into how innovative technologies can be harnessed to meet basic psychological needs and facilitate the acquisition of complex grammatical structures.

Methodology

Learning environment design

Ethical approval was obtained from the university's research ethics committee prior to initiating the study, ensuring adherence to ethical guidelines. We developed a VR-based grammar learning environment using the Unity engine, which was subsequently exported as an APK file for deployment on the Meta Quest 3 headset. The application immersed learners in a structured scenario designed to cultivate intrinsic motivation and support the construction of a coherent grammatical framework centered on the structure and meaning of the present perfect tense. An AI-driven grammar instructor, implemented by integrating the DeepSeek API via carefully designed prompts, was embedded in the system to deliver personalized explanations and adaptive feedback based on each learner's input and error patterns. Within the VR environment, scripted NPCs guided learners through a series of interactive tasks designed to illustrate the use of the present perfect tense in contextually relevant dialogues. Following these guided interactions, learners engaged in game-based activities that required them to apply the grammar rules in practical scenarios. Additionally, learners could autonomously navigate to a dedicated virtual zone to initiate a conversational session with the AI instructor, allowing them to deepen their understanding through self-directed dialogue and scaffolded practice. The learning sequence concluded with a reflection phase, where learners summarized not only the grammatical content covered but also their metacognitive awareness of how the system's feedback and guidance supported their comprehension. To sustain engagement, a reward mechanism tied to task completion and performance was incorporated, fostering a sense of accomplishment and collaborative learning dynamics.

The course design is structured around SDT, emphasizing supporting autonomy, competence, and relatedness needs to enhance learner intrinsic motivation and knowledge acquisition (see Table 1). Example strategies include integrating game elements to cultivate interest in grammar learning and foster internal motivation that satisfies autonomy and competence needs. Additionally, creating a

collaborative learning environment reduces the influence of the mother tongue while fostering a sense of community to address the need for relatedness. A detailed report will be provided at the assessment phase of the course, outlining points, achievements, and areas for improvement. This report supports the mastery of skills and enables independent planning. The design encourages autonomy by leveraging AI exploration and self-paced learning, allowing students to review content and set personal goals, ultimately promoting a proactive and independent learning experience.

Table 1 Self-Determination Theory in course design

	Instruction	Assessment
Autonomy	• Learners can freely explore different regions of the “Grammar Continent,” guided by NPCs to discover content tailored to their learning needs. • Learners decide their own sequence when studying with AI-driven instructors, such as whether to learn tense structures or meanings first. • Learners determine their learning path, skipping familiar content to focus directly on areas where they are weak. • In the forest fire scenario, learners freely choose sentence input order and expression methods—the system imposes no single correct answer. • Learners may pause, replay, or skip AI explanatory dialogues at any time, maintaining complete control over their learning pace.	The report allows learners to decide whether to view detailed explanations, enabling them to take full control of their learning outcomes.
Competence	• Gradual Difficulty Mode: First learn structures through simple memorization → Then apply them in semantic scenarios → Finally produce 5 sentences quickly during timed firefighting tasks. • Instant Feedback: If student input is incorrect, the AI-driven instructor guides students to think through their mistakes, explaining issues and teaching correct grammar. • Mastery Reinforcement: A “Fire Rescue” progress bar displays upon task completion.	The report clearly displays points, specific error type statistics, and improvement suggestions, allowing learners to clearly see “how much I have mastered.”
Relatedness	• Scripted NPCs appear as “adventure companions,” addressing learners by name in a friendly tone. • AI-driven instructors provide real-time praise based on learner performance, fostering a sense of partnership. • Scripted NPCs join learners in confronting the “Continental Grammar Collapse” crisis, forming a shared narrative of “saving the world together.” 4. Learners can ask questions anytime to the AI-driven instructor, who provides patient answers to enhance the sense of support.	At the end of the report, an AI-driven instructor provides a personalized encouragement letter and allows learners to leave feedback.

Experimental design

The designed course aimed to address the challenges faced by Chinese learners in learning and using English grammar. We further conducted an experiment to investigate the potential of a VR-facilitated AI-driven instructor, English Adventure, in language education, providing actionable insights for educators and technology developers to refine immersive educational tools and enhance student learning outcomes. Twenty postgraduate and undergraduate students at a university in Hong Kong were recruited for this study (10 females and 10 males, aged 22–32). They come from education and technology-related disciplines and may therefore be more technology-friendly and open to novel learning tools than the average learner population, introducing a potential selection bias and limiting the external validity of the findings, such as results may not generalize as readily to learners from non-technical fields or with lower technological affinity. All participants have a basic level of English proficiency and are non-native speakers, with limited prior VR experience. The experiment took place in a controlled classroom, utilizing VR headsets to teach the present perfect tense through an interactive fire-extinguishing scenario (see Figures 1 and 2).

Figure 1 Learners experience the task session

Figure 2 Learners experience the AI-driven English instructor session

This study employed a mixed-methods approach, combining qualitative and quantitative analyses to assess the effectiveness of English Adventure. It was structured into four key phases: pre-test, instructional intervention, post-test, and semi-structured interview, as detailed in Figure 3. This phased design facilitated a thorough evaluation of the course's impact on participants' grammar acquisition and engagement.

Figure 3 Experimental procedure

The instructional intervention stage lasted approximately 90 minutes, included a 20-minute VR session using the English Adventure, supplemented by additional activities. The process began with a 15-minute pre-test to assess intrinsic motivation and establish a baseline of grammar knowledge, followed by a 10-minute in-class learning session focusing on present perfect tense structures. The core intervention featured a 15-minute interactive VR experience, where participants engaged with English Adventure and non-player characters (NPCs) to explore the meaning of the present perfect tense through gamified tasks, such as a fire-extinguishing scenario. Each VR session was deliberately kept short, lasting approximately 15 minutes, to minimize fatigue and technical barriers for novice users. The brevity of the session will be taken into account when interpreting the results, particularly with respect to potential novelty effects and the risk of insufficient dosage for achieving longer-term learning gains. A 10-minute reflection period allowed learners to summarize their learning, reinforcing comprehension. The sequence concluded with a 15-minute post-test to measure improvements in intrinsic motivation and grammar mastery, as well as a 20-minute semi-structured interview to gather qualitative feedback on participants' experiences.

Measurements

Motivation scale: We adopted the Intrinsic Motivation Inventory (IMI) to assess students' intrinsic motivation (McAuley et al.,1989). The scale was validated by previous studies (Monteiro et al., 2015). The IMI used in this study measures several key subscales. Example items include interest/enjoyment ("I think I will enjoy reading this material," "I think I will find this material very interesting," and "I believe reading this material will be fun"), perceived competence ("I think I will understand this material pretty well" and "I believe I will understand this material very well, compared to other students"), and pressure/tension ("I don't think I will feel nervous at all while reading this material", "I expect to feel very tense while reading this material," and "I don't think I will enjoy reading this material very much").

Grammar test: Participants completed pre- and post-knowledge tests to evaluate grammar proficiency. These tests were developed by Grammar Friends 5, published by Oxford University Press, and reviewed by three in-service schoolteachers in mainland China (examples are provided in Appendix 1).

Subjective experience: Interview questions were designed by the research team. Example interview questions include "How are you feeling about this way of learning?"
"How do you find this environment helpful or challenging for learning?" "As you learn the present perfect tense, how helpful have you found this environment and the AI instructor?" "How is this style of learning different from the way you learned English before? Which one do you prefer?"
"If you could improve this learning environment, what would you suggest? Why?"

Data collection and analysis

We evaluated the impact of English Adventure on students' learning of the present perfect tense, from both quantitative and qualitative perspectives. The participants (N = 20) completed pre- and post-tests immediately before and after a 30-minute VR session. These tests evaluated two learning outcomes: intrinsic motivation and grammar knowledge. We then investigated students' subjective experiences of using VR to learn English grammar through interviews (lasting 20 minutes). The participants' background information is shown in Appendix 2.

To ensure data reliability, a Z-score analysis was performed, identifying three participants as outliers. Their data were subsequently excluded. Paired samples T-tests, conducted using SPSS, were utilized to analyze the differences between pre- and post-test scores, providing statistical insights into learning gains. Complementing these quantitative measures, semi-structured interviews were conducted post-intervention, with the responses transcribed. The first and third authors followed the six steps of thematic analysis (Braun &Clarke, 2006) to collaboratively code the interview data. This process began with the two researchers immersing themselves in the data through repeated reading to gain familiarity, followed by the generation of initial codes. Through iterative discussions, these codes were then collated into potential themes, which were reviewed and refined to ensure they were coherent, distinct, and

accurately reflected the dataset. Finally, each theme was clearly defined and named to capture its essence, and all themes were listed in a report.

Results

Impacts on intrinsic motivation

As demonstrated in Figure 4 and Table 3, using English Adventure substantially enhanced intrinsic motivation. After the intervention, the IMI (M = 5.34, SD = 0.58) showed a significant improvement compared to the baseline (M = 4.53, SD = 0.54). This observation was substantiated by a statistically significant difference (t (16) = -4.72, p < 0.001). The magnitude of the effect was considerable, as indicated by a Cohen's d of -1.15. However, the broad confidence interval (95% CI: [-1.75, -0.52]) and the low correlation between pre- and post-test scores (r = 0.20, p = 0.44) suggest variability in the effect across participants, which may be attributable to individual differences among learners. These likely included differences in individuals' cognitive and affective engagement with the virtual environment, their perceived usefulness of the AI instructor, and their baseline familiarity and comfort with immersive technology, collectively influencing the motivational outcomes.

Figure 4 Pre- and Post-IMI Box Plot

Table 3 Pre- and Post-IMI Paired T-test

Variable Pair	Mean (SD)	Correlation (P)	T	df	P (Two-tailed)	Cohen's d [95% CI]	Hedges' Correction [95% CI]
Pre-IMI	4.53 (0.54)	0.20 (0.44)	-4.72	16	<.001	-1.15 [-1.75, -0.52]	-1.09 [-1.67, -0.49]
Post-IMI	5.34 (0.58)						

Impacts on grammar knowledge

Figure 5 and Table 4 show that the intervention significantly improved participants' knowledge acquisition. Post-test scores (M = 12.65, SD = 1.62) were substantially higher than pre-test scores (M = 9.71, SD = 2.82), with a large mean difference of 2.94 points (t (16) = -5.33, p < 0.001). A strong pre-post correlation (r = 0.59, p = 0.01) further confirmed the consistency and substantial effect of the intervention. The effect size was robust, with a Cohen's d of -1.29 (95% CI [-1.93, -0.63]), indicating both statistical and practical significance.

Figure 5 Pre- and Post-Knowledge Box Plot

Table 4 Pre- and Post-Knowledge Paired T-test

Variable Pair	Mean (SD)	Correlation (P)	T	df	P (Two-tailed)	Cohen's d [95% CI]	Hedges' Correction [95% CI]
Pre-Knowledge	9.71 (2.82)	0.59 (0.01)	-5.33	16	<.001	-1.29 [-1.93, -0.63]	-1.23 [-1.84, -0.60]
Post-Knowledge	12.65 (1.62)						

Subjective experiences with English Adventure

The current study explored learners' experiences with English Adventure in learning the present perfect tense, and the themes that emerged from interviews with 20 participants included the benefits of VR for grammar learning, the challenges encountered, and suggestions for improvement.

Benefits of grammar learning

As illustrated in Appendix 3, the qualitative data from participants' interviews provide rich, multifaceted evidence. Notably, 90% of participants highlighted "immersion and engagement" as a core benefit, describing how the VR environment created a realistic, captivating space that enhanced learning outcomes. For instance, Student 1 praised the "Immersive environment that attracts attention, with scene changes enhancing focus and understanding of the present perfect tense." In contrast, Student 16 noted it fostered "A highly engaging learning experience" through vivid simulations. Similarly, Student 9 appreciated the "Immersive scenarios that enhance learner involvement," underscoring how the VR environment bridged abstract grammar to tangible contexts.

The immersive quality was complemented by "interactivity and motivation" (60%) and "concrete understanding" (45%). Sixty percent of participants emphasized increased learning motivation and participation, often attributing this to the use of gamification and interactivity. Student 2 exemplified this by stating, "VR is engaging and immersive; the game format boosts enthusiasm and participation." Student 14 described it as "Fun like playing a game, VR immersion increases learner participation." This theme aligns with reports of heightened motivation, as Student 5 mentioned, "High interactivity enhances immersion, AI feedback stimulates learning enthusiasm and involvement."

Additionally, 45% reported improved understanding of concrete concepts, with VR-facilitated AI-driven instruction aiding comprehension of complex tenses. Student 6 noted "Gamification and VR immersion deepen understanding," and Student 20 said "AI and VR make learning fun and help me remember." Some participants highlighted fun and motivational aspects, such as Student 18's view that "VR and AI give immediate help, making hard grammar easier to learn and more fun." Overall, these experiences

suggest VR-facilitated AI-driven instructor integration transforms passive learning into an active, memorable process.

Challenges of using English Adventure

The students' interview also revealed challenges of using English Adventure. Approximately 55% of participants reported "Physical discomfort and device issues," including dizziness and strain affecting concentration, as evidenced by Student 1's account, "Unskilled operation, dizziness," and Student 11's "Physical strain from extended wearing." Additionally, 25% reported "Distraction and over-reliance on AI," with Student 18 expressing concern that "Over-reliance on AI reduces independent and creative thinking." Thirty-five percent encountered "Technical difficulty," such as initial setup challenges noted by Student 6, "Technical difficulty in initial setup." They also highlight the challenges of hardware discomfort, including device weight, distractions, and physical discomfort.

Suggestions for using English Adventure

Participants suggested key improvements in three areas (see Appendix 3): device comfort (50%), instructional design (40%), and interactivity (30%). For device optimization, participants like the accounts of Student 4, Student 16, and Student 20, "Make the device lighter." At the same time, Student 15 suggested "Engage other senses for interaction, such as voice input, to reduce dizziness." In instructional design, Student 7 proposed "Adjust teaching steps, let AI teach first before entering the scene.", Student 9 suggested "Integrate traditional teaching method.", and Student 18 accounted "Encourage independent thinking with open questions and less AI help." For enhanced interactivity, Student 11 called for "Add interactivity to gamified stages," Student 5 suggested "Add more practice sessions after the learning phase," and Student 17 suggested "Add audio cues for better navigation." Student 6 suggested "strengthen AI guidance" to boost engagement.

Discussion

This study examines the effect of English Adventure on learners' intrinsic motivation and understanding of the present perfect tense, addressing a critical need to assess immersive tools in SLA. The findings underscore substantial variations in strategy implementation and learning outcomes among participants. Quantitative data demonstrate that the designed instructor significantly enhances grammatical mastery, as evidenced by substantial improvements in test scores, indicative of a more profound understanding of the tense. However, the impact on intrinsic motivation appears more complex, suggesting a multifaceted interplay of factors influencing this attribute. Our research findings underscore the potential of the VR-facilitated AI-driven instructor as an effective pedagogical tool for grammar learning, while revealing nuances in motivational dynamics that warrant further exploration to optimize its educational benefits.

English Adventure and intrinsic motivation

The first research question focuses on intrinsic motivation. Post-IMI scores show that more than half of the participants reported a significant increase, indicating that VR has a positive effect on engagement. This aligns with SDT, which emphasizes autonomy, competence, and relatedness as core motivators (Ryan & Deci, 2000). English Adventure supports autonomy through choice-driven tasks, competence through skill-appropriate challenges, and relatedness via interactions with AI-driven instructors and NPCs. Other theories can also provide support for enhancing learning motivation through the characteristics of VR. Flow theory suggests that VR's immersive gamification creates an optimal challenge-skill balance, boosting engagement (Csikszentmihalyi, 1990), which shows VR enhances motivation by providing tailored challenges that match learners' skill levels. Activity theory indicates that VR's interactive environment structures learning as a mediated activity, enhancing motivation through social and tool-based interactions (Engeström, 2014). The avatars in English Adventure create a dynamic learning environment, where motivation is amplified with them. Embodied Cognition Theory (ECT) suggests that physical actions in VR, such as extinguishing fires, link bodily engagement to cognitive processes, thereby reinforcing intrinsic drive (Wilson, 2002). So that learning in a VR environment can stimulate physical actions to strengthen cognitive connections. Cognitive Load Theory (CLT) suggests that VR's contextualized feedback reduces extraneous load, thereby freeing cognitive resources for motivation and further supporting SDT's competence component (Sweller, 1988). The learning content learners mastered was feedback from the situation rather than abstract conceptions and characters, enhancing learners' sense of competence and intrinsic motivation, thus improving learning outcomes.

However, several factors will affect the research outcomes. First are prior VR exposure and technological familiarity. Participants with previous VR experience achieved noticeably larger motivation gains than first-time users, who often felt initial overload from simultaneously mastering controllers, navigation, and language content. Secondly, Susceptibility to VR. Some participants experienced physical discomfort, such as dizziness, which may reduce motivation by undermining competence and autonomy, as per SDT (Wang et al., 2017). Previous studies also reported a similar situation, noting that a part of users experience dizziness during and after VR exposures (Rebenitsch & Owen, 2016), and dizziness reduce their motivation by frustrating their basic psychological needs outlined in SDT (Ryan et al., 2006), and they suggested optimizing technical performance to enhance usability and providing users with various comfort options and interaction choices (Davis et al., 2014). The third one is baseline grammar proficiency. Learners starting with lower pre-test scores showed the most improvement in their grammar knowledge, yet displayed smaller and more variable motivation gains, often because open-ended tasks caused frustration when feedback was not immediate. These findings highlight VR's ability to enhance intrinsic motivation through SDT principles while indicating the need for personalized interventions to address barriers. These individual differences highlight the current one-size-fits-all design as a key limitation and point directly to the need for adaptive features.

English Adventure and grammar acquisition

The second aspect of RQ1 addresses the extent to which English Adventure enhances learners' cognitive mastery of the present perfect tense, filling a gap in empirical evidence on the role of immersive

technologies in tackling abstract grammar challenges for non-native speakers. Quantitative results from pre- and post-tests demonstrated a significant improvement in knowledge scores. This aligns with SDT, which suggests that students' autonomy is supported through interactive choices in these tasks, enhancing learners' sense of control. VR's immersive scenarios also support the competence need by allowing learners to apply the tense in contextualized tasks, such as fire-extinguishing activities. Based on CLT, VR can reduce extraneous mental effort by simulating real-world contexts, allowing for a focus on understanding the tense, which supports SDT's competence motive (Sweller, 1988). ECT further indicates that physical interactions in VR, such as manipulating virtual objects, help learners internalize grammatical rules, thereby facilitating the competence need (Wilson, 2002).

Moreover, the research findings suggest individual differences in technology adaptation, which directly echo Heift's (2008) emphasis on learner variability in feedback interaction, and align with Lalira et al.'s (2024) recent insights into user diversity in emerging VR/AI-facilitated educational environments. Learners with lower baseline scores may have benefited less due to unfamiliarity, highlighting a gap in adaptive personalization. These findings will provide educators with directions for future development of educational technologies and course design.

English Adventure experiences

The RQ2 delves into learners' subjective experiences, addressing the gap in qualitative insights on the practical implementation of English Adventure in grammar teaching. All participants reported positive aspects, noting that the gamified immersion in VR environments made abstract tense usage more accessible. This result aligns with the advocates of SDT, as VR supports autonomy through self-paced exploration and competence through engaging, skill-appropriate tasks. The AI-driven instructor's real-time feedback reduced cognitive load, supporting autonomous learning and competence, as per SDT and CLT (Sweller, 1988). Relatedness was enhanced through virtual interactions with AI and NPCs, creating a sense of connection.

However, some participants noted drawbacks, leading to passive reliance on guided answers rather than active internalization. This can be explained by CLT, where excessive guidance increases extraneous load, reducing cognitive effort for independent learning (Sweller, 1988). Aligning with the study of Davis et al. (2014), technical issues, such as hardware discomfort, also posed challenges, potentially disrupting the immersive experience by causing physical discomfort or distraction that hindered learners' engagement with the virtual environment. These findings indicate that while VR is transformative, its effectiveness depends on balancing guidance with opportunities for independent thought.

These findings demonstrate the transformative potential of English Adventure in grammar education, particularly for mastering the present perfect tense, while highlighting the complexity of motivation dynamics. The interactive nature of VR tasks, such as fire-extinguishing scenarios, supports the autonomy need by allowing learners to make choices. AI-driven feedback supports competence and relatedness needs by offering real-time, personalized guidance. Specifically, the VR-facilitated AI-driven

instructor significantly enhances grammatical mastery by providing immersive, contextualized learning experiences that align with SDT's emphasis on competence, as evidenced by the percentage of participants showing improved test scores. However, the variability in motivation outcomes underscores the need for tailored approaches to sustain SDT-driven motivation.

These findings also address a critical gap in SLA by demonstrating how immersive technologies can overcome the limitations of traditional grammar instruction, which often struggles to contextualize abstract concepts, such as the present perfect tense (Al-khresheh, 2024; Ellis, 2006; Huang et al., 2021; Parmaxi, 2023). Simultaneously, they emphasize the need to balance VR's immersive benefits with AI-facilitated, individualized support mechanisms that address diverse learner needs, such as varying levels of familiarity with VR technology or physical comfort. Aligned with SDT, the findings advocate for a balanced integration of VR with individualized support. The collaboration of VR and AI offers promise but requires careful design to avoid constraining independent thought. The study recommends that educators, technology developers, and course designers leverage VR as a scalable supplement to traditional methods, enhancing hardware comfort and developing adaptive AI-driven exercises that promote active learning. By carefully balancing immersive technology with individualized support, VR can revolutionize grammar instruction while fostering equitable, engaging, and effective learning experiences.

Conclusion

This study confirms the significant potential of VR-facilitated AI-driven instruction in enhancing Chinese learners' intrinsic motivation and cognitive mastery of the present perfect tense, as evidenced by substantial test score improvements and qualitative reports of deeper comprehension. The impacts on intrinsic motivation, though notable, are complex, influenced by individual differences and tempered by physical discomfort, underscoring the need for tailored interventions. Students' subjective experiences highlight VR's immersive and engaging qualities, yet technical and ergonomic challenges suggest areas for refinement.

The study on the VR-facilitated AI-driven instructor for learning the English present perfect tense reveals critical limitations. Firstly, the small, homogeneous sample of 20 undergraduate and postgraduate students from a Hong Kong university limits the generalizability of the study, as it overlooks diverse learner profiles, including varying language proficiency and cultural backgrounds, due to the study being conducted solely among Hong Kong Chinese learners. Secondly, the short-term, single-session design is inadequate for assessing long-term impacts on motivation and grammar retention, which may be influenced by novelty effects, where the novelty effect may exaggerate the observed motivation enhancement. Additionally, there is a lack of control group comparisons with traditional teaching methods, making it difficult to isolate the specific contributions of VR, AI, and the SDT framework. Finally, the immersive demands of VR and reported discomfort, such as dizziness, which can vary significantly across different age groups and physical constitutions, may potentially overwhelm learners, thereby

undermining the efficacy of SDT. These issues necessitate broader, longitudinal research to validate the efficacy of VR in grammar education.

Future research on the VR-facilitated AI-driven instructor for grammar learning should focus on several key directions. First, expanding studies to include larger and more diverse sample sizes is crucial for validating findings and enhancing the generalizability of research. Second, research should integrate multimodal data—such as eye-tracking and physiological measures—to provide a richer, more objective elucidation of learner intrinsic motivation and cognitive engagement, moving beyond self-reported metrics. A third critical direction involves developing and exploring adaptive AI systems, not only for personalizing grammar exercises but also for encouraging critical thinking and fostering the internalization of rules through prompts that facilitate independent reflection. Furthermore, investigating the role of AI in mitigating VR-induced discomfort and technically enhancing motivation through improved ergonomics and stability remains a vital area of inquiry. These research strands will ensure VR's sophisticated evolution as an effective, comfortable, and motivating tool for English grammar learning and broader educational applications.

Declarations

Ethics approval statement

Ethics approval was obtained from the Education University of Hong Kong. The approval body is the Human Research Ethics Committee (HREC) of the Education University of Hong Kong. We confirm that all research was performed in accordance with the relevant guidelines/regulations applicable when human participants are involved. The approval number is 2024-2025-0301, and the date of approval is 3 January 2025. The scope of approval includes research in the course TLS3003 "Curriculum and Assessment" at the Education University of Hong Kong. The project is titled "Empowering digital learners in higher education through case-based creativity and entrepreneurship with virtual reality artifacts."

Informed consent statement

Informed consent was obtained in the classroom at the Education University of Hong Kong. Written informed consent was obtained on January 9, 2025, by the corresponding author from students in the course TLS3003 "Curriculum and Assessment." The scope of the consent includes the introduction of the research and the student participants from the target course. The data collected will be used to reveal students' learning experiences with virtual reality from the designed course. The participants consent to the possibility that the research results may be published in journal articles and conference presentations. The study does not involve vulnerable individuals, nor does it involve payment or other forms of incentivization. The study is interventional research.

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Figures

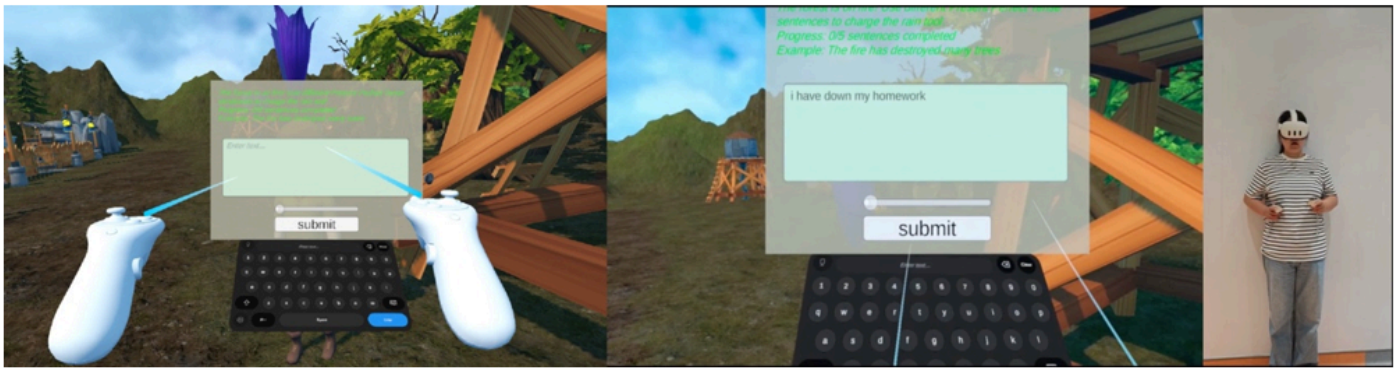


Figure 1

Learners experience the task session



Figure 2

Learners experience the AI-driven English instructor session

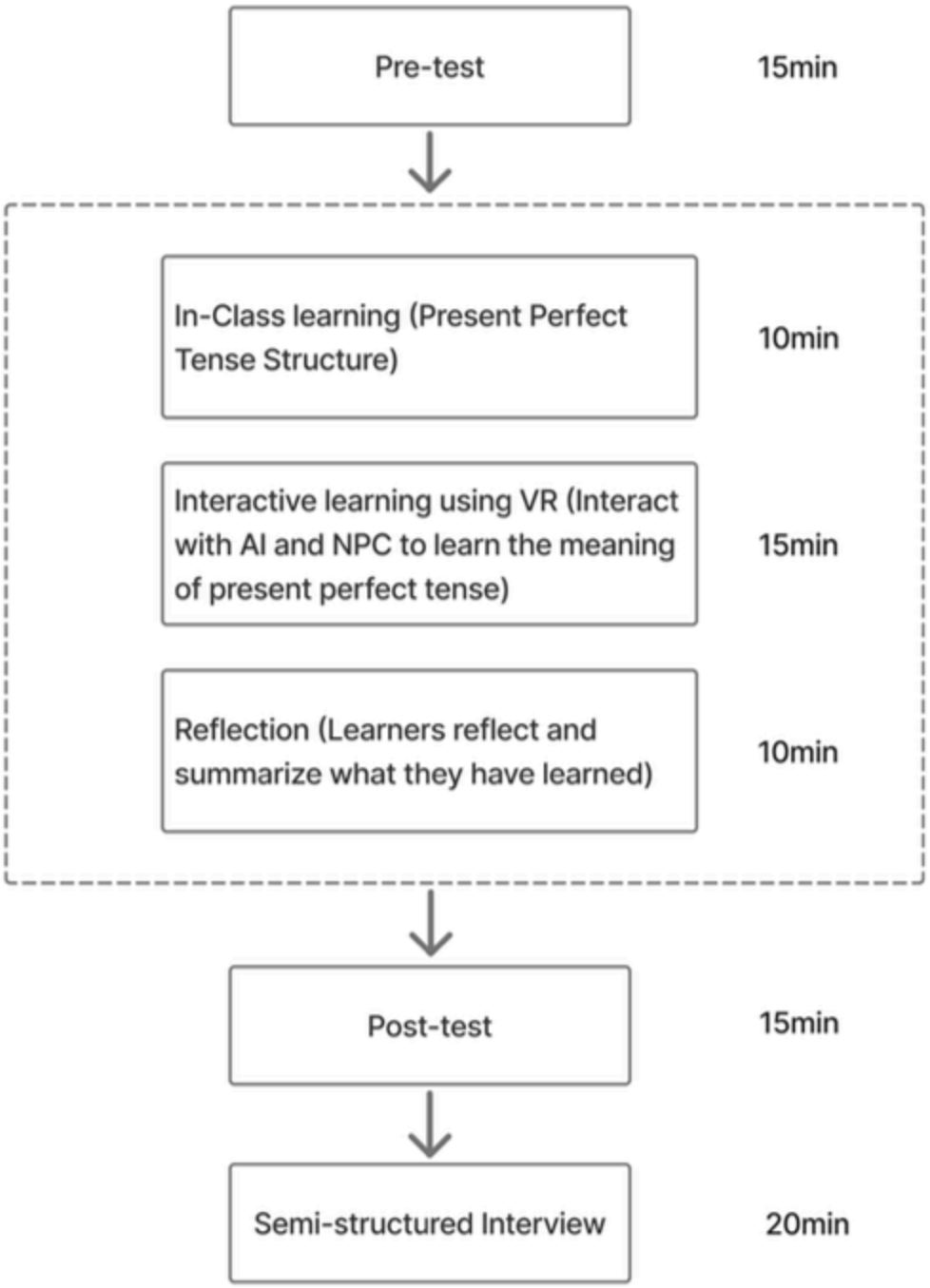


Figure 3

Experimental procedure

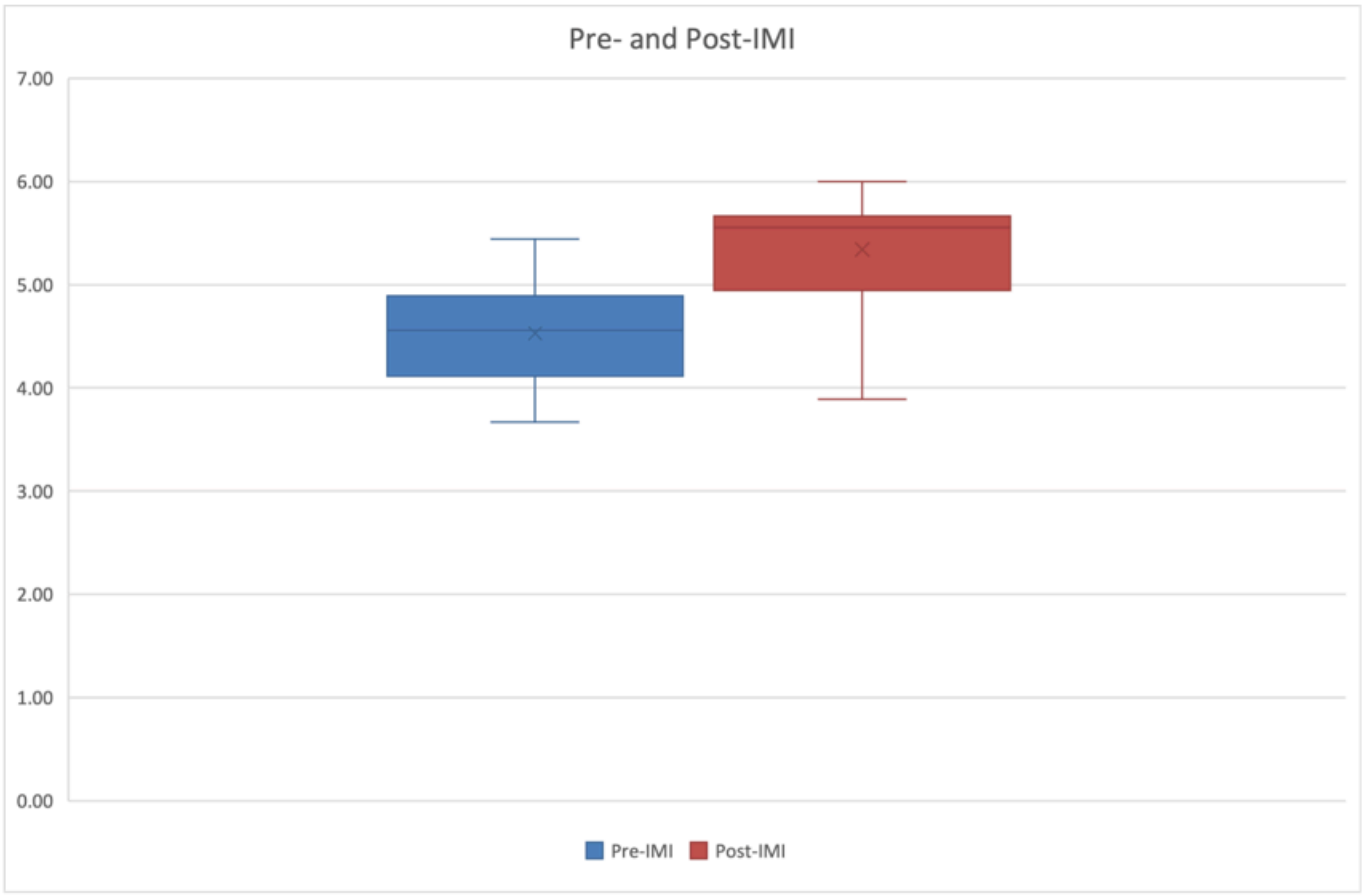


Figure 4

Pre- and Post-IMI Box Plot

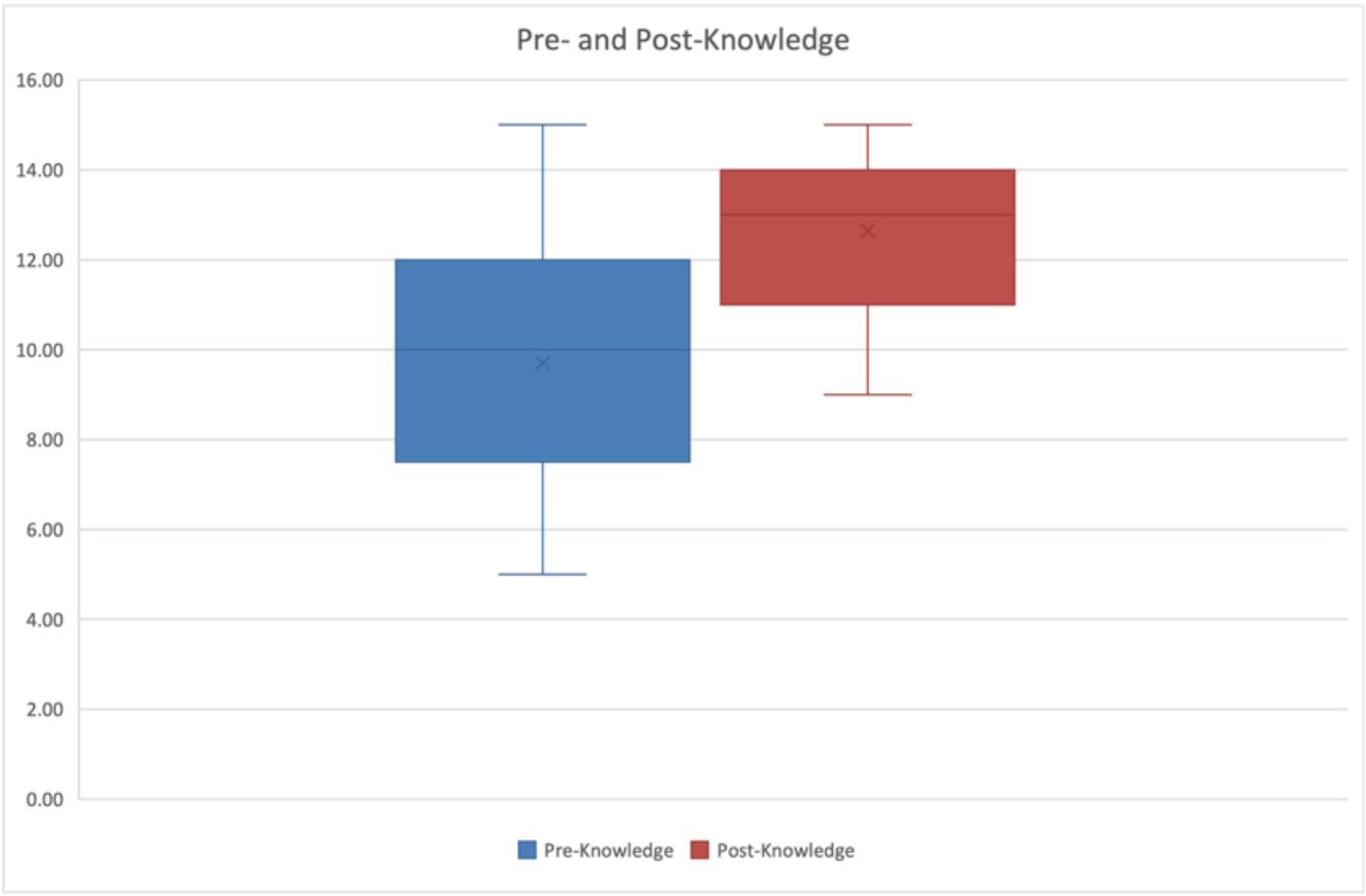


Figure 5

Pre- and Post-Knowledge Box Plot

Supplementary Files

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- Appendixupdated.docx