Designing Effective Mathematics Learning: Augmented Reality Framework Development via the Fuzzy Delphi Method

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***Abstract*—In the current era where Augmented Reality (AR) is making significant impact on various aspects of education, its specific role in mathematics education is of crucial significance. A quantitative research design was employed, utilizing the Fuzzy Delphi technique to collate opinions from a diverse group of 17 experts drawn from fields such as education, User Interface/User Experience (UI/UX), mobile app development, AR/VR, mathematics, computer science, and educational technology. The data analysis indicated a consensus among the experts on the key elements necessary for creating effective AR applications in mathematics education, as evidenced by values exceeding 75% agreement, with a maximum acceptable dispersion of opinions (d) $\leq$ 0.2, and a minimum consensus measure (fuzzy score, $\geq$ α-cut value larger than 0.5). The findings underscore the importance of the identified components in the design and development of AR applications for mathematics education and signal significant potential for promoting technology-enhanced active learning in the educational field.**

***Index Terms*—Mathematics Education, Fuzzy Delphi Technique, Framework Design, Expert Consensus**

I. INTRODUCTION

Innovative teaching methods, such as AR, can enhance educational experiences by fostering engaging and stimulating learning environments [1]-[3]. Despite numerous educational applications, few studies have focused on AR for mathematics, with some only examining a single aspect of AR [4]-[6]. These studies emphasize the need to explore AR's impact on math learning and achievement and call for more user-friendly AR applications.

Various frameworks have been proposed for AR educational applications, with some focusing on language studies [7] or chemistry topics [8][9]. Rahman et al. [10] developed a framework targeting calculus but primarily emphasized human-system interactions, leaving a gap for guidelines in developing successful math-focused AR applications.

A variety of frameworks have been proposed for AR educational applications. While the framework by [7] is tailored for language studies, the one by [8] and [9] is designed for chemistry topics. Rahman et al. [10] developed a framework targeting the calculus subject in mathematics. However, their framework primarily accentuates interactive learning based on human-system interactions, leaving a gap in the provision of guidelines for developing a successful AR application that focuses on mathematics to enhance student understanding and performance.

Addressing this research gap, this study aims to validate a comprehensive framework for an AR-based mathematics learning approach using the Fuzzy Delphi Method. The goal is to facilitate the design and implementation of effective AR applications that enhance math learning experiences, ultimately contributing to improved student outcomes.

II. RELATED WORK

Studies by [8] and [9] proposed a framework for developing mobile AR applications for learning chemical bonds. The framework incorporated principles from the cognitive theory of multimedia learning and visual design principles. In contrast, the framework by [10] focused on an interactive AR learning system for calculus. The study examined human-human and human-system interactivity and their effects on learning experiences and performances. A study by [11] indicated that usability factors such as learnability, satisfaction, memorability, simplicity, privacy, and security are vital. Research by [12] aimed to identify factors influencing learning experiences that could be addressed by advanced technologies.

Meanwhile, [7] presented a framework focused on integrating AR and pedagogy to improve reading comprehension in special education. The study suggested using schoolbooks enhanced with AR content, real-time feedback, and personalized content. The Cognitive Theory of Multimedia Learning (CTML) [9] is essential for AR applications with multimedia elements. The interactive system component by [10] was focusing on human-system interaction.

Furthermore, learnability, satisfaction, memorability, simplicity, privacy, and security are crucial factors for designing mobile applications [11]. Verification similar to [12] is conducted in this study, focusing on the effects of multimedia elements in the learning process. Pedagogical theories in [7] was included in the present framework, as AR applications align with constructivism and constructionism principles.

education, potentially amplifying the framework's effectiveness and adaptability. Furthermore, we plan to detail the technical underpinnings, decisions, and iterations involved in the construction of this framework in our future works.

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