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Innovation in Numeracy Learning Through Immersive Media for Pre-Service Teachers in Professional Education

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ABSTRACT

This research presents an innovative approach to numeracy instruction for pre-service elementary school teachers using holographic images. The primary contribution is the integration of low-cost, mobile-based holographic prototyping within teacher education to enhance spatial reasoning, foster interdisciplinary learning, and support experiential pedagogy. This research aims to analyze prospective teachers' perspectives on holographic media in numeracy learning, with a focus on their experiences in designing and evaluating hologram prototypes for classroom use. A qualitative methodology was adopted, involving 59 pre-service teachers from an elementary teacher education program. Data collection utilized questionnaires and semi-structured interviews, with thematic analysis employed to identify key patterns and themes. Participants engaged in an iterative design process, developing and testing several holographic prototypes, which resulted in a truncated pyramid configuration optimized for mobile-based projection. The analysis identified four principal themes: interdisciplinary applicability, pedagogical strategies for young learners, development of holographic problem-solving skills, and improved spatial–structural understanding. The findings suggest that holographic learning activities enhance student engagement, deepen conceptual understanding, and strengthen both spatial and collaborative skills. This study extends the literature on numeracy and STEM education by illustrating the effective integration of immersive holographic media into pre-service teacher training as a practical and pedagogically valuable instructional innovation.

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A. INTRODUCTION

Numeracy literacy is a fundamental competency for 21st-century learners to navigate real-life challenges. Numeracy extends beyond the ability to calculate; it also encompasses the capacity to interpret, analyze, and apply numerical information across diverse everyday contexts. Nevertheless, numerous studies indicate that many students continue to experience difficulties in grasping numeracy concepts, particularly when confronted with authentic problem situations (Díez-Palomar et al., 2023; Winarni et al., 2025). At the same time, rapid advances in information and communication technology have significantly influenced education, particularly in terms of pedagogical approaches and learning tools. In the digital age, the utilization of technology serves as an effective means of making learning attractive and engaging (David & Weinstein, 2024; Duarte et al., 2025; Ibrahim et al., 2025). Numeracy is a significant educational aspect that involves comprehending, implementing, and disseminating quantitative information across various life contexts (Adelia et al., 2024; OECD, 2019).

In line with technological developments, the implementation of innovative learning strategies supported by technology has been shown to enhance students' literacy and numeracy skills (Anggun, 2025; Arifin et al., 2025; Lee, 2023). Such learning strategies can be conducted via several technological media, one of them being immersive media. Immersive technology-based learning media has begun to be implemented in response to rapid technological developments (Sviridova et al., 2023; Tan, 2023; Xu, 2025). This media utilizes three types of technologies, such as Augmented Reality, Virtual Reality, and Mixed Reality, which is a combination of the two earlier technologies (Crogman et al., 2025; Kaplan-Rakowski & Meseberg, 2019). Meanwhile, empirical studies have demonstrated that immersive media conveys an abstractive mathematical concept visually, thereby raising creativity among students in the process of learning mathematics (Chonchaiya & Srithammee, 2025; Hidajat, 2024; Kumar et al., 2021; Muhaimin & Juandi, 2023; Su et al., 2022).

Immersive learning technologies put much effort into balancing between the real world and the virtual worlds (Alhazzaa & Yan, 2025; Aufenanger et al., 2025; Muzata et al., 2024). These technologies offer hands-on learning experiences that enhance understanding and retention. More specifically, immersion aids function as learning media and analytical tools that support and enhance the learning process in educational environments (Izouaouen et al., 2025; Osypova et al., 2021; Tene et al., 2024; Wang & Huang, 2025; Yadav, 2025). Despite previous research focusing on immersive media and contextual pedagogy in numeracy learning, most studies have focused on junior and senior high school students. Research that combines these approaches is still limited to the numeracy skills of prospective teachers (Mohammad et al., 2023). Given that prospective teachers must have innovative learning experiences, they are expected to design inventive, attractive, and relevant numeracy learning for classroom practice.

Therefore, this study aims to address this gap by assessing the abilities of prospective teacher education students through the integration of immersive media with real-world contexts. The specific objectives of this study are to analyze the outcomes, attitudes, and methods that students can use to learn about the development of both approaches to improve numeracy literacy. For future educators, the development of practical skills in implementing numeracy education will be supported by immersive and contextual technologies. Technology plays a twofold role in mathematics instruction: it facilitates the delivery of complex content and enhances student engagement to promote deeper understanding. According to Mazana et al. (2018) Such tools foster learning by allowing students to engage in operations associated with abstract mathematical concepts, thereby enhancing understanding and strengthening problem-solving competence. These immersive tools support various learning activities that contribute to achieving inclusive classroom practices (Touel et al., 2020). However, significant barriers persist, including high costs, the need for specialized equipment, and the requirement for institutions to establish comprehensive training programs to ensure effective implementation (Mohammad et al., 2023). This training requires a high level of teacher guidance, benefiting both teachers and students in multiple ways during instruction (Tashtoush et al., 2022).

Technology has facilitated mathematics education by enhancing students' understanding and increasing their engagement. The use of online learning platforms and environments has helped students actively learn and understand concepts (Atteh et al., 2023). Digitally facilitated

collaborative learning can improve the accuracy of mathematical problem-solving (Kusuma et al., 2023). Conversely, MOOCs have demonstrated their potential to enhance mathematical proficiency and improve outcomes (Boaler et al., 2018). However, several challenges remain to be overcome, such as teacher rigor, the need for diligent study, and the difficulty of accessing technology (Sharzadin et al., 2019). Therefore, although technology has much potential to improve education, its effectiveness ultimately lags behind the implementation of integration and pedagogy (Radka & Štefan, 2019).

Holographic media at the educational level have introduced both unanticipated benefits and challenges. For example, holograms can be effectively used to support learning related to spatial visualization in mathematics and technology. As dynamic and visually engaging tools, holographic displays can enhance student motivation, thereby fostering greater engagement in learning (Lastya et al., 2025; Salloum et al., 2024). However, like other emerging technologies, holograms also face user-related implementation challenges, including limited infrastructure, operational constraints, and resource availability (Cáceres et al., 2024). Holographic devices in the class also require supportive training related to these skills for proper implementation. Thus, successful implementation will depend on whether it matches the curriculum goals, learning objectives, and student needs (Radović, 2024).

This study was driven by the need to investigate the potential of innovative educational technologies to enhance learning and teaching. Immersive media can create engaging and dynamic learning environments, yet traditional pedagogical approaches still largely prioritize a more individualized approach. The effectiveness and acceptability of immersive devices, particularly holographic media, have not been well explored in the context of pre-service teacher education, where students are continually developing their instructional skills and pedagogical work skills. The purpose of this study is to investigate how pre-service teachers interact with holographic media by describing their abilities, perceptions, and challenges that arise during the process of determining their potential or shortcomings in education. This study also aims to provide examples of pre-service teacher skills and knowledge in integrating holographic media into teacher education programs. Therefore, the results of this study are expected to improve student learning and contribute to the advancement of technology-based education.

Despite the growing adoption of immersive technologies in mathematics education, empirical research on integrating holographic media into numeracy instruction for pre-service elementary school teachers remains scarce. Existing studies predominantly address primary or secondary school students, leaving the experiences, design processes, and pedagogical evaluations of prospective teachers largely unexplored. This research gap is significant because pre-service teachers are key agents in translating technological advancements into effective classroom practices. Mastery of numeracy content alone is insufficient; pre-service teachers must also acquire pedagogical and technological skills to create engaging and meaningful learning experiences (Ahmichane et al., 2025; Meletiou-Mavrotheris & Prodromou, 2016; Nupen & Jagernath, 2024; Wang & Reimann, 2025). Opportunities to interact with holographic media during teacher education programs can foster spatial reasoning, instructional creativity, and technology-integrated pedagogy. In the absence of such experiences, future teachers may lack the confidence and practical skills required to implement innovative numeracy instruction

in elementary classrooms. Accordingly, this study investigates the use of holographic media in numeracy learning from the perspectives of pre-service elementary school teachers. By examining their experiences designing and evaluating hologram prototypes, this research offers empirical evidence on the pedagogical potential, challenges, and instructional value of holographic learning in teacher education.

B. METHODS

This study adopted a qualitative approach to explore educators' (pre-service teachers') views and experiences regarding the use of holographic media in classroom instruction. Questionnaires and interviews were employed as the primary data collection instruments, as they enable an in-depth analysis of participants' ideas, perceptions, and experiences. Accordingly, this study aimed to examine the factors influencing students' adoption of holographic technology in the classroom, as well as its perceived benefits and challenges.

This study involved 59 students enrolled in the Pre-Service Teacher Professional Education (PPG) and Elementary School Teacher Education (PGSD) programs at a private university in Bandung, who served as prospective teachers in the development and testing of an immersive numeracy learning innovation using holographic images. Participants engaged in a multi-stage process that included the design, development, and testing of a mobile-based holographic prototype to support numeracy learning in primary schools. Data were collected via questionnaires to provide an overview of students' perceptions and experiences of holographic media in numeracy instruction. To gain deeper insights and confirm the questionnaire findings, five students were selected for interviews using purposive sampling. The criteria for selecting interview participants included active involvement in the development and testing of the prototype, a clear understanding of the application of holographic media in numeracy learning, and a willingness to provide in-depth reflections through semi-structured interviews.

Semi-structured interviews were employed as the primary data collection method in this study because they allowed for clearly formulated questions while maintaining a focus on the main research topics. The interviews explored students' perceptions of the advantages of holographic media, its role in the educational process, and the challenges encountered in its use. With participants' consent, each interview, lasting approximately five to ten minutes, was audio-recorded and subsequently transcribed to provide contextual depth for analysis.

Semi-structured interviews further reinforce previous research findings, indicating that qualitative approaches are particularly effective in uncovering attitudes toward educational technology; therefore, this study employed such interviews. For example, qualitative methods used to explore students' opinions of e-examinations yielded positive outcomes (Rostaminezhad, 2015). Earlier studies on teachers' attitudes toward ICT show that qualitative approaches help reveal factors influencing technology adoption (Clipa et al., 2023). Based on this premise, the interview design aimed to gather diverse views from prospective educators on holographic media, seeking insights into its potential use in education.

This study employed ATLAS.ti software to manage a large volume of data and systematically identify coding categories and themes, thereby ensuring a credible and comprehensive analysis of participants' perspectives (Moreno-Guerrero et al., 2020). The analysis commenced with data familiarization, achieved through repeated examination of open-ended questionnaire

responses and interview transcripts. Initial codes were developed to identify significant data segments pertinent to the research objectives. Related codes were grouped into potential themes, which were then reviewed to ensure coherence and representativeness across the dataset. Each theme was clearly defined and named to delineate its scope and significance. The final stage involved reporting the themes and their interpretations to present a comprehensive account of participants' perspectives (Dawadi, 2020). The resulting themes captured key aspects of participants' experiences, including their attitudes, perceived benefits, and challenges associated with incorporating holographic media into educational settings.

Several strategies were implemented to strengthen the trustworthiness of the findings. Data triangulation involved comparing questionnaire and interview results to ensure consistency across sources. Researcher reflexivity was maintained throughout the analysis to reduce interpretive bias. An audit trail was established by systematically documenting coding decisions and theme development within ATLAS.ti, which promoted transparency and analytical rigor. Collectively, these methods enhanced the credibility and dependability of the qualitative results. The hologram construction required simple, low-cost materials, including mica plastic, scissors, tape, and a YouTube video displaying four sides of a moving object. The video was played on a mobile phone or tablet, with an estimated cost of approximately Rp 25,000 per group. To ensure successful project completion, instructors provided clear guidance, particularly in constructing the four-sided reflective space necessary to project the holographic image onto the mobile device screen.

C. RESULT AND DISCUSSION

This research was conducted on October 6, 2024, with two different classes of pre-service professional education teachers. The holographic learning activity was organized into three stages. First, students engaged in scenario design using rulers, scissors, pens, acetate sheets, scratch paper, and tape, which lasted approximately 25 minutes. Second, they explored and constructed prototype designs for a duration exceeding 100 minutes. Finally, students completed a summary, responded to a questionnaire, and reflected on the activity during the closing 25 minutes. Overall, the holographic learning session had a total duration of 150 minutes. Throughout the design process, students experimented with several prototypes before arriving at a successful model, as illustrated in Figure 1.

1. Prototype Progress

Figure 1 illustrates a sequence of spatial structure prototypes developed by students for educational holographic display purposes. Each design was intended to produce a stable and distinctive holographic effect when positioned on a mobile phone screen.



a. Cube-shaped Prototype



b. Square Pyramid Prototype

Figure 1. Series of Prototypes

The initial attempt involved a cube-shaped structure intended to display holograms. However, testing revealed that the cube was geometrically incompatible with the projection of holograms on a mobile phone screen (Figure 1a). As a next step, students designed a square pyramid structure to address these shortcomings (Figure 1b). Despite these improvements, the prototype was unsuccessful, as the pyramid configuration did not produce the desired holographic effect during trials using mobile video material.

2. Successful Prototype: Truncated Pyramid

To overcome these challenges, students refined their approach by designing a truncated pyramid. Adjustments to the angles and dimensions aligned the structure with the optimal configuration for holographic projection, as shown in Figure 2.



Figure 2. Student activities when identifying holographic representations

Figure 2 illustrates students' engagement in hands-on activities related to the identification and testing of holographic representations. The image shows participants examining light reflection, adjusting the position of the truncated pyramid, and evaluating the clarity of the projected image during experimental trials. This design proved significantly more effective, successfully projecting holograms using a YouTube video displayed on a mobile phone as the medium. The successful projection is shown in Figure 3.



Figure 3. Completed Hologram

Figure 3 shows the final holographic projection produced by placing a transparent truncated pyramid on a mobile phone screen. The butterfly image appears suspended in three-dimensional space because light reflects from the four inclined surfaces of the pyramid. This figure demonstrates the successful combination of geometric design, material selection, and viewing parameters required to achieve a clear holographic effect.

3. Result of Holographic Display

A successful holographic prototype projecting a butterfly image through a transparent truncated pyramid is shown in Figure 2. The pyramid structure is derived from the reflection of the display device onto a specific area to create this holographic image. Test results showed that viewing in dim light significantly improves visual quality, both in terms of depth and clarity. To maximize hologram visibility, observations were conducted in dim lighting, with the setup positioned under a table (see Figure 2). This exercise verified that the truncated pyramid design met the optical and spatial requirements for creating a holographic display. Therefore, these observations provide in-depth practical insights into the potential application of the holographic prototype in educational technology.

They employed an iterative design approach, emphasizing the importance of experimental prototyping in the development of educational technology. Prototypes were created to address various design challenges and then identified. In addition to establishing a foundation for future research on strategies for integrating hologram technology, this process yielded several benefits in terms of conceptual understanding and technical skills. Furthermore, this process is expected to make learning interactive and enjoyable.

Four major research themes were identified to examine the educational impact of holographic learning: its application across different subjects, instructional strategies for teaching younger students, the development of problem-solving skills through holography, and the enhancement of spatial and structural understanding. These themes provide a foundation for higher-level interpretations of the role of holography in teacher education and classroom practice. The identified themes were derived from questionnaire responses and semi-structured interview data, capturing participants' experiences throughout the design, testing, and evaluation of holographic prototypes for numeracy learning.

This study is grounded in the assumption that holography can serve as a motivational tool to sustain students' interest in complex scientific concepts, foster technical and spatial skills,

and thereby support interdisciplinary education at advanced levels. The topics discussed illustrate how holography can stimulate creativity, hands-on experience, critical thinking, and problem-solving, forming a foundation for deeper interdisciplinarity. These themes are further examined in terms of their broader educational benefits for classroom practice, as illustrated in Figure 4.

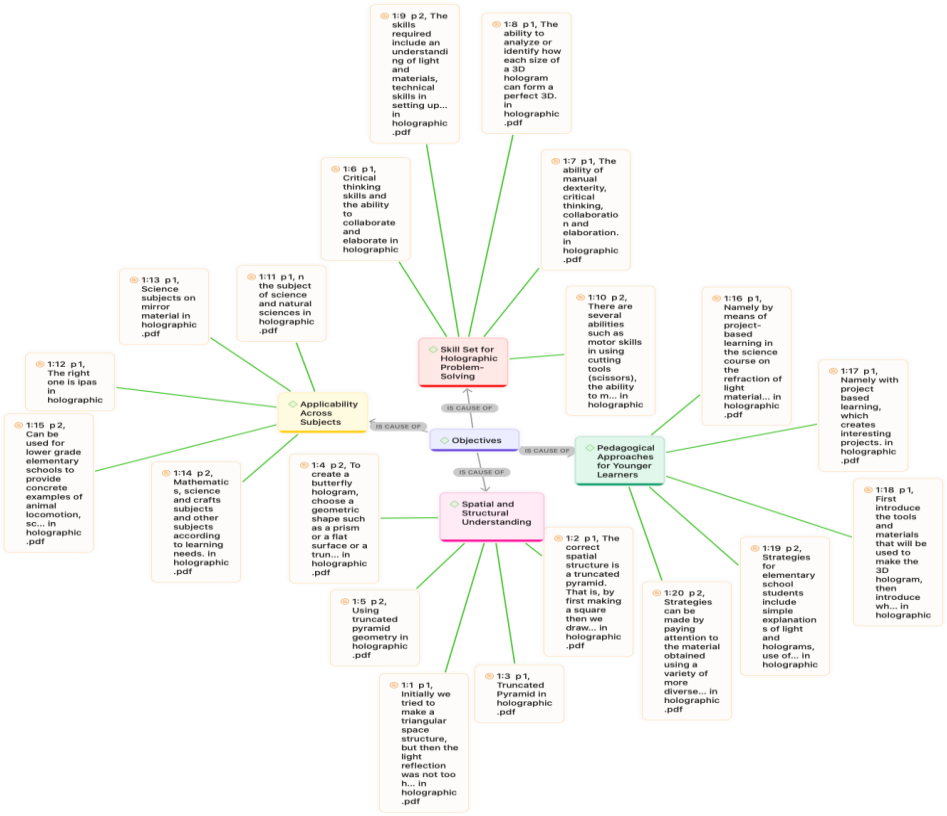


Figure 4. Research Themes

4. Applicability Across Subjects

Analysis of participants' reflections suggests that the hologram design activity can be integrated into various subjects, including mathematics, science, and art, during the prototype construction process. The application of holographic activities across diverse disciplines is a key focus, highlighting the educational benefits these practices can offer. This aligns with S. H. Alshammari's (2019) argument that immersive media, through holographic activities, enhance virtual environments and transform human communication in the digital age. A pyramid was created, resulting in a unique butterfly-shaped hologram because its geometric shape reflected more light, thereby creating a multi-interpretable projection. This activity demonstrates clear interdisciplinary applications: science students examine the properties of light and materials, mathematics students apply geometric concepts and measurements, and art students hone their creativity and practical skills. This activity builds organization, creativity, timeliness, and spatial skills. Holography aids comprehension, especially for younger learners, through clear examples, collaboration, and structured teaching. It links real phenomena and integrates knowledge for holistic education.

Holography supports hands-on learning across science, mathematics, and the arts, while its interdisciplinary approach encourages critical thinking and problem-solving in complex subjects (Smith, 2008). Earlier research has indicated that students find increased creativity and involvement in the outreach activity when holography is used (V. Kumar et al., 2023). Also, STEAM education emphasizes creativity in scientific inquiry and technological advancement through the inclusion of the arts (Ma et al., 2022). It fosters innovative, cross-disciplinary problem-solving and equips students to tackle real-world challenges. Experiential learning through holography could be a way to combine the technical, creative, and scientific skills for enhanced engagement and understanding.

In particular, elementary and middle school students will be able to reap the benefits of gaining technical and scientific skills through hands-on, practical, and creative learning experiences (Kim et al., 2014) We argue that discovery-based learning also enhances scientific creativity because students engage in the active investigation of these topics. Project-based learning through STEAM promotes the application of knowledge in new ways, creativity, and persistence within classroom activities. In contemporary education, methods of creative visualization and silent learning have become components that raise the intellect of students who can think critically about a problem and work toward solving it (Ozdemir & Dikici, 2016). Moreover, evidence indicates that an encouraging and creative classroom climate increases student engagement and scientific motivation. This finding suggests that, for pre-service teachers, holographic media serves both as a visualization tool and as a pedagogical training resource for developing numeracy learning activities.

5. Pedagogical Approaches for Younger Learners

Interview data indicated that participants prioritized step-by-step guidance, clear explanations, and hands-on activities as essential for effective use of holographic media with younger learners. This method, applied to both early and upper grade levels, leverages the potential of holography to help students grasp complex scientific concepts through accessible and comprehensible activities. Through the process of creating holograms, students can directly explore the principles of light and reflection within an experiential learning framework. Group work fosters communication and teamwork skills that are essential for project completion. The process is presented in clear, step-by-step stages to ensure understanding and enable students to replicate the hologram-making process. Scientific concepts are explained using real-world examples and simple language rather than technical terminology. The projects demonstrate how classroom learning can be applied to real-life contexts by integrating science, mathematics, and art. Student engagement increases when abstract concepts such as animal movement or the Earth's rotation are connected to familiar everyday activities. Thus, holography gives a hands-on, group-based, and strong teaching method for children.

Both clear explanations and hands-on activities are important in helping children understand concepts such as light and reflection. Previous studies attest that practical exercises enhance students' understanding of scientific concepts (Alshammari et al., 2020). Moreover, technological developments in physics instruction promote active learning by simplifying complex topics. A justification-based, inquiry approach provides a better conceptual understanding; thus, the PODE (Predict, Observe, Discuss, and Explain) essentially improves

scientific process skills among students (Herdianto et al., 2021). New teaching approaches bring abstract concepts to life for students, engaging them and ensuring motivation remains high (Li et al., 2024; Li, 2022).

Experiential, collaborative, and incremental approaches increasingly highlight emerging best practices in STEM education. Working in groups enables students to reason through complex scientific concepts by engaging with real-world challenges (Fan & Ye, 2022). While inquiry-based experiments have great potential to develop critical thinking and problem-solving skills, the infusion of art in STEM (STEAM) education promotes creativity, interdisciplinary thinking, and motivation among students as they relate better with challenging science topics (Chen & Chen, 2021). Side by side, these methods highlight holography as a progressive pedagogy helping educators simplify complex science while fostering students' creativity, collaboration, and higher-order thinking. These results indicate that holographic media functions as both a visualization tool and a pedagogical training resource for pre-service teachers in the development of numeracy learning activities.

6. Holografik Skill Set for Holographic Problem-Solving

This theme emerged from students' engagement in selecting materials, adjusting geometric dimensions, and resolving projection failures during the development of holographic prototypes. The course outlines the skills required to create holograms, including material selection based on optical principles, technical setup and operation, design for clear image projection, and precise measurement. STEM education stresses creativity, accuracy, and collaboration (Amelia & Santoso, 2021). PjBL-STEM enhances knowledge and creativity (Hanif et al., 2019), with teamwork fostering participatory problem-solving (Othman et al., 2022). Arts integration adds multidisciplinary creativity (Conradty & Bogner, 2018). Projects build skills, deepen engagement (Meester et al., 2020) and link theory to practice for future work (Juškevičienė et al., 2021). In this regard, holographic activities demonstrate the value of project-based STEM learning in developing technical accuracy, as well as creative problem-solving and collaboration skills. The findings suggest that holographic media serve as both a visualization tool and a pedagogical training resource for pre-service teachers engaged in developing numeracy learning activities.

7. Spatial and Structural Understanding

Analysis of participants' responses indicated that repeated experimentation with geometric forms, especially the truncated pyramid, improved their comprehension of spatial structure and light reflection. The subject of spatial and structural comprehension highlights the major skills and elements that make up holographic images effectively. In this research, the hologram of a butterfly, the design that proved most successful, employed a truncated pyramid structure, which optimized light reflection, as illustrated in Figure 5.



Figure 5. Truncated pyramid model built by students

Attempts also involve the use of prisms or flat surfaces, but geometry interferes with the refraction of light and the focus of the projected image. Material choice is also crucial, as transparent acrylic is the most effective for generating refraction. Apparent and stable holographic imaging also requires a directional light source precisely aligned at the correct angle. The analysis above indicates that expertise in the knowledge of light and materials, technical ability in equipment setting, creative design skills, and construction precision are necessary attributes for achieving such results. Thus, holography has a multidisciplinary application across science, mathematics, and crafts. Simplified explanations, accessible content, and experiential learning make it more understandable for younger learners. Group work promotes both technical understanding and pedagogical effectiveness.

Researchers consistently emphasize the importance of spatial awareness and geometric reasoning in science and technology. Spatial awareness and geometric reasoning play a critical role in optics, holography, and other related visual-spatial domains. Spatial skills are crucial for STEM students because they aid in understanding and solving complex challenges (Uttal et al., 2013). A meta-analysis found that spatial skills improve with practice and support math learning and reasoning (Moreno-Guerrero et al., 2020), while training also helps narrow the gender gap in science careers (Ganley et al., 2014).

Holography offers a practical approach for cultivating visual-spatial skills through experiments with truncated pyramids and other geometric shapes. Students can visualize abstract optical principles through direct manipulation of light patterns and reflections. Advanced technologies make complex optics easier to grasp Urness et al. (2015) highlighted GRIN lenses for teaching light manipulation, while Ren et al. (2020) showed how machine learning and 3D holography can be combined with low-cost materials. Together, these studies show holography's potential to build spatial skills, clarify abstract concepts, and support experimental design. The results demonstrate that holographic media serve as both a visualization tool and a pedagogical training resource for pre-service teachers involved in designing numeracy learning activities.

The findings suggest that holographic learning activities enable pre-service teachers to develop numeracy-related competencies, including spatial reasoning, instructional creativity, and problem-solving skills. These results are consistent with the study's objective to examine

pre-service teachers' perspectives on the design and implementation of holographic media for numeracy learning.

D. CONCLUSION AND SUGGESTIONS

Based on the main findings, this study concludes that holographic learning activities provide meaningful learning experiences for pre-service elementary school teachers by integrating iterative prototyping, spatial reasoning, and interdisciplinary learning. The results demonstrate that the process of designing and refining holographic prototypes, particularly the transition to a truncated pyramid structure, enhanced participants' understanding of geometric, optical, and structural concepts while fostering problem-solving and technical skills. Furthermore, the findings suggest that holography facilitates pedagogical approaches appropriate for younger learners through experiential, collaborative, and stepwise learning activities, which render abstract concepts more accessible. The four emergent themes applicability across subjects, pedagogical strategies for younger learners, holographic problem-solving skills, and visual-spatial, structural understanding highlight the potential of holography as an innovative and feasible instructional approach in numeracy and STEM-oriented learning. Future research is encouraged to investigate age-appropriate instructional designs, interdisciplinary implementations beyond STEM, and the long-term development of technical, collaborative, and spatial skills through low-cost holographic technologies in diverse educational contexts.

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