

EXPLORING STUDENT LEARNING EXPERIENCE THROUGH IMMERSIVE VIRTUAL REALITY A STEAM LEARNING MEDIUM TO SUPPORT NUMERACY LITERACY IN ELEMENTARY SCHOOL

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Abstrak

This study aims to explore the learning experiences of elementary school students through Immersive Virtual Reality (IVR) as a STEAM learning medium to support numeracy literacy. The study used a qualitative exploratory approach with a phenomenological nuance, involving 10 elementary school students selected by purposive sampling as key informants. Data were collected through participant observation, in-depth interviews, documentation, and field notes. The results revealed three main themes: (1) the use of IVR provides an immersive and exploratory learning experience that increases student engagement despite technical barriers; (2) STEAM learning occurs through exploration, interaction, discussion, and problem-solving; and (3) numeracy literacy emerges through the identification of numerical information, measurement, comparison, and contextual decision-making. Overall, IVR functions as an immersive, collaborative, and contextual learning environment that supports elementary school students' numeracy literacy.

Keywords: *Immersive Virtual Reality; STEAM; experiential learning; numeracy literacy; elementary school.*

1. INTRODUCTION

Literacy and numeracy are core competencies that serve as prerequisites for successful learning in elementary school and also as a foundation for cross-subject learning at subsequent levels. Ideally, learning in elementary school is directed towards enabling students to understand text-based information, reason about data or numbers, and solve contextual problems through active and meaningful learning experiences. However, international empirical evidence shows that Indonesia's achievements are still lagging behind, particularly in the domains of reading and mathematics, indicating serious challenges to the quality of the learning process that directly impact student literacy and numeracy (OECD, 2023). This gap is also evident in national indicators through National Assessment data, which shows that the proportion of students achieving minimum competency standards in literacy and numeracy in 2024 is uneven, necessitating more effective and measurable learning interventions in schools (Education Standards, Curriculum, and Assessment Agency, 2025a, 2025b).

Improving literacy and numeracy in elementary schools should ideally rely not only on practice exercises, but also on designing learning experiences that enable students to build conceptual understanding, transfer, and reasoning. In reality, learning practices in elementary schools are often dominated by expository approaches and routine activities that provide little space for exploration,

visualization of abstract concepts, and authentic problem-solving. Therefore, improvements to learning strategies and the use of data-driven innovations are needed (Ministry of Primary and Secondary Education, 2025). In recent years, Immersive Virtual Reality (IVR) technology has been promoted as an option to enrich learning experiences because it enables three-dimensional visualization, interaction, and a stronger sense of presence than conventional digital media. The effectiveness of IVR for learning can be explained through the Cognitive Affective Model of Immersive Learning (CAMIL), which emphasizes how technological factors such as immersion and interactivity influence cognitive-affective processes and ultimately impact learning outcomes (Makransky & Petersen, 2021).

However, VR-based learning outcomes are not always consistent if the intervention design, learning outcome measures, and terminology used are not uniform across studies. A recent systematic review highlighted the persistence of inconsistencies in intervention design and outcome measurement across IVR studies, which can lead to less robust findings under certain conditions (Jongbloed et al., 2024). VR does have a positive impact on learning gains, with higher levels of immersion tending to yield greater gains than semi-immersive or non-immersive systems, although the effect is strongly influenced by duration, context, and learning design (Villena-Taranilla et al., 2022). Therefore, VR is not a silver bullet; its effectiveness depends on the design of learning experiences that align with objectives (Petersen et al., 2022; Zekeik et al., 2025).

In terms of learning approaches, STEAM (Science, Technology, Engineering, Arts, and Mathematics) is increasingly being used to improve learning quality by integrating various disciplines into project- or inquiry-based activities. Empirical evidence in Indonesia shows that STEAM-inquiry-based digital modules can improve students' literacy skills in different school contexts (Susanta & Susanto, 2025). Other findings also show that STEAM-based digital learning can have a positive impact on improving elementary school students' numeracy literacy, although its effectiveness depends on the quality of the media and activity scenarios used (Hidayanthi et al., 2024).

However, a significant research gap exists: the limited number of studies that systematically integrate Immersive Virtual Reality Learning Experiences with STEAM approaches directly aimed at improving elementary school students' literacy and numeracy. Many VR studies focus on specific subjects or outcomes, such as mathematical creativity or STEM literacy, and have not specifically measured literacy-numeracy as a minimum competency targeted by national assessment policies (Hidajat et al., 2024; Widiyatmoko et al., 2023). Furthermore, many STEAM studies still utilize non-immersive digital media, thus underutilizing the opportunities to leverage IVR's affordances—presence, three-dimensional interactivity, and spatial exploration—to strengthen numerical-text comprehension and reasoning (Petersen et al., 2022; Zekeik et al., 2025).

The urgency of this research is further strengthened by national indicators showing that some students still have not achieved minimum competency standards in literacy and numeracy. Therefore, schools need learning innovations that are not only engaging but also proven to measurably improve minimum competency. The National Assessment data published through the 2024 literacy and numeracy dataset provides an empirical basis for schools and researchers to design more targeted interventions based on minimum competency achievement (Education Standards, Curriculum, and Assessment Agency, 2025a, 2025b).

Based on this gap, this research contributes in two ways. First, it provides a theoretical understanding of how the design of Immersive VR Learning Experiences (STEAM) can align with the cognitive-affective mechanisms described in CAMIL, such as motivation, engagement, cognitive load, and knowledge transfer (Makransky & Petersen, 2021). Second, it provides a practical contribution in the form of an empirical understanding of student experiences that can inform the development of STEAM-based IVR learning products and their implementation and evaluation tools. This allows elementary school teachers to strengthen literacy and numeracy through exploration, problem-solving,

and multimodal representation activities that are difficult to achieve in conventional learning (Villena-Taranilla et al., 2022; Jongbloed et al., 2024).

Based on the description, this study aims to explore the learning experiences of elementary school students in using Immersive Virtual Reality as a STEAM learning medium, describe how students experience the process of exploration, interaction, and solving STEAM problems in a virtual environment, and explore how students use numeracy literacy to solve contextual problems in the learning. By placing student experiences as the center of the study, this article is expected to enrich the conceptual understanding of the function of IVR as a STEAM learning medium in a more contextual and pedagogical way, while providing practical recommendations for teachers, schools, and learning media developers in supporting the strengthening of numeracy literacy at the elementary school level.

2. LITERATURE REVIEW

Immersive Virtual Reality Learning Experience Berbasis STEAM

Immersive Virtual Reality (IVR) is a form of learning technology that creates a three-dimensional simulated environment so that students experience learning as if they were in a real-world context. Visual, audio, and navigation interactions in a virtual space designed for learning objectives provide an intensive and realistic experience. The main advantage of IVR lies in its ability to provide a sense of presence, namely the feeling of being fully in the virtual environment that stimulates cognitive, affective, and motoric engagement of students simultaneously, thus differing from conventional two-dimensional media (Radianti et al., 2020; Slater, 2018).

Immersive Virtual Reality Learning Experience (IVR-LX) in the STEAM context can be understood as a learning experience that combines an immersive three-dimensional virtual environment, real-time interactions, and meaningful tasks to foster cross-disciplinary knowledge construction. Meta-analytic evidence suggests that the effectiveness of IVR in education depends heavily on instructional design and alignment with learning objectives, not solely on the level of immersion (Makransky & Lilleholt, 2018; Coban et al., 2022). In terms of engagement, VR-based learning has been shown to increase student motivation and active participation due to the exploratory and contextual nature of the experience, while also helping students build a more intuitive understanding of cause-and-effect relationships in science and mathematics concepts through three-dimensional representations (Parong & Mayer, 2018; Merchant et al., 2014; Wu et al., 2020).

Theoretically, IVR is rooted in constructivism and experiential learning, which emphasize learning through direct experience, ranging from concrete experience, reflection, conceptualization, to active experimentation (Kolb, 1984; Makransky & Petersen, 2021). The concept of sense of presence is an important foundation for the effectiveness of IVR because it allows students to feel truly present in the virtual environment, thereby increasing authentic experiences and memory retention (Cummings & Bailenson, 2016). From a cognitive perspective, IVR activates multimodal processing through the integration of visual, audio, and kinesthetic, in line with multimedia learning theory, which emphasizes that the combination of structured representations can enhance conceptual understanding and long-term retention, as long as cognitive load is well managed to avoid information overload (Mayer, 2014; Sweller et al., 2019). However, IVR implementation faces challenges such as teacher readiness, content design, and infrastructure needs, so its success is highly dependent on strong pedagogical support and a planned implementation strategy (Radianti et al., 2020; Howard et al., 2021).

Digital Learning Media and Immersive Virtual Reality

Learning media is a crucial component in the educational process because it serves as an intermediary connecting learning materials with students' learning experiences. The use of digital technology has expanded the characteristics of learning media from static forms to interactive, multimodal, and adaptive media, allowing material to be presented through a combination of verbal and

visual representations that support more structured and meaningful learning (Cavanagh & Kiersch, 2023). This diversity of representation forms allows learning media to become a pedagogical instrument to increase student engagement, accessibility, and participation (Zakariyah et al., 2024), as also found in the use of digital media in elementary schools, which is related to student motivation and academic achievement (Bintoro et al., 2024).

As a form of digital learning media, IVR allows students to feel as if they are in a digitally simulated learning space, with characteristics of immersion, interactivity, and exploration of three-dimensional space that are difficult to achieve through conventional media (Buchner & Mulders, 2026). IVR also has the potential to change the position of students from recipients of information to active actors in the learning process through observation, exploration, object manipulation, and problem solving in situations that resemble real contexts, although its implementation faces challenges such as device availability, costs, and educator competence (Orhak & Çağiltay, 2024; Sakr & Abdullah, 2024).

The immersive characteristics of IVR provide opportunities to deliver learning experiences that are difficult to achieve through conventional media, such as observing objects from various perspectives, moving within a virtual environment, and manipulating objects according to learning scenarios. In the context of STEAM learning, virtual environments can be used to present problems that require the integration of various disciplines, allowing students to observe scientific phenomena, design solutions through engineering activities, use mathematical concepts in measurement, and integrate elements of art in the design process. IVR's position as a medium that provides a context for students to use numeracy knowledge and skills in the exploration and problem-solving process makes it relevant for strengthening numeracy literacy naturally, without placing it as a separate activity from STEAM learning.

Numeracy Literacy as a 21st Century Competency

Numeracy literacy is an individual's ability to understand, use, and reflect on mathematical concepts to solve problems in a variety of real-life contexts. This ability extends beyond arithmetic operations to include analyzing data-based information, interpreting mathematical representations, and making rational decisions based on quantitative information. Global assessment frameworks emphasize that numeracy literacy is closely related to the ability to formulate, apply, and interpret mathematics in a variety of situations, thus viewing numeracy as a cross-contextual competence that supports individuals' active participation in modern society (OECD, 2023).

In Indonesia, numeracy literacy is positioned as a minimum competency that supports lifelong learning, so its measurement is designed contextually and requires reasoning, not memorization. The Minimum Competency Assessment Framework emphasizes that numeracy encompasses content (numbers, geometry and measurement, data and uncertainty, algebra), cognitive processes (knowing, applying, reasoning), and context (personal, socio-cultural, scientific). Therefore, numeracy learning ideally provides experience with meaningful, multi-representational problems and encourages mathematical argumentation (Ministry of Education, Culture, Research, and Technology, 2022).

A contextual approach has proven effective in improving numeracy literacy because it helps students understand the meaning of numbers in everyday life and reduces the tendency to memorize formulas without understanding the concepts. Quasi-experimental findings on probability even show differences in numeracy literacy achievement between classes implementing Problem-Based Learning and Discovery Learning, while also confirming that numeracy reinforcement requires scenarios that require problem-solving and explanation of reasons, not just mechanistic exercises (Asri & Maysarah, 2024). Numeracy literacy is also not only formed in schools, as informal numeracy activities at home also contribute to the development of children's numerical abilities (Tomasetto et al., 2022), while for groups of children with specific learning support needs, numeracy reinforcement requires a systematic and gradual program design (Hudson et al., 2025).

Numeracy literacy is also closely related to the quality of individual participation in modern life, which is filled with data and number-based claims. Therefore, its strengthening needs to be directed at the habit of testing the meaning of numbers in everyday activities (Patterson, 2025). Good numeracy measurement instruments need to consider content validity, construct validity, and reliability to truly measure quantitative reasoning in context, not just computational ability (Purnomo et al., 2022). In turn, teacher professional development also determines the success of numeracy strengthening, as teachers need to be able to orchestrate mathematical discussions, use multiple representations, and utilize formative assessments to assess student reasoning (LINCS, 2024; Department for Education, 2023). The notion of quantitative literacy also emphasizes the importance of the ability to use mathematics reflectively in social and democratic life (Steen, 2001), which provides an important foundation for exploring how learning environments such as STEAM-based IVR can facilitate elementary school students' numeracy literacy practices in a natural and contextual manner.

3. METHOD

Type of Research

This study uses a qualitative approach with an exploratory qualitative research type colored by a phenomenological approach, because it aims to understand, describe, and explore in depth the learning experiences (lived experiences) of elementary school students when using immersive Virtual Reality as a STEAM learning medium in supporting numeracy literacy. A qualitative approach was chosen because this study seeks to understand the meaning given by students to a learning phenomenon that is still relatively new, with data collection carried out in a natural setting and data analysis inductive (Creswell & Poth, 2018). This type of exploratory research was chosen because the phenomenon being studied has not been explored in depth, especially in the context of elementary education in Indonesia, so this study is not intended to test causal relationships or make statistical generalizations, but rather to describe in detail how students experience, interpret, and respond to the learning they undergo (Stebbins, 2001). The paradigm underlying this research is interpretive-constructivist, which assumes that reality is socially constructed and understanding of a phenomenon is obtained through interpretation of the participant's own point of view, with the researcher acting as the main instrument (human instrument).

Participants

Participants in this study were 10 (ten) elementary school students who had participated in the learning process using immersive Virtual Reality as a STEAM learning medium. The determination of participants was carried out using a purposive sampling technique, namely a sampling technique with certain considerations according to the objectives and needs of the research, not based on the principle of statistical population representation (Sugiyono, 2019). Participant criteria included students who were actively enrolled in the target class for the implementation of immersive VR-based STEAM learning, had participated in at least one learning session using the device, and were in a physical and psychological condition that allowed the use of the VR device. The ten participants were selected proportionally by considering gender diversity, academic ability level, and prior experience with digital technology, so that the data obtained could represent a richer variety of learning experiences. Class teachers were involved as supporting informants to obtain triangulation data.

Data Collection

Data were collected through four complementary techniques to obtain rich and in-depth data (technique triangulation). First, participant observation was conducted to record students' behavior, expressions, interactions, levels of engagement, and natural responses during the learning process, with the aid of observation guidelines and field notes. Second, in-depth interviews were conducted semi-

structured with all participants to explore students' experiences, perceptions, feelings, and meanings of immersive VR-based STEAM learning, with interview guidelines written in simple language appropriate to the cognitive development of elementary school-aged children. Third, documentation in the form of photos, videos of learning activities, and student work was collected as supplementary data and as a verification tool. Fourth, researchers compiled field notes and reflective journals to document important contexts and dynamics that emerged outside the observation and interview guidelines, thereby enriching the holistic interpretation of the data.

Data Analysis

Data analysis used an interactive qualitative data analysis model consisting of four components: data collection, data condensation or reduction, data presentation, and conclusion drawing and verification, which took place simultaneously and continuously, not linearly (Miles et al., 2014). Data reduction was carried out through open coding which was then grouped into certain categories and themes (axial coding), for example themes regarding learning motivation, understanding of numeracy concepts, technical obstacles, and students' emotional responses. The reduced data were presented in the form of narrative descriptions accompanied by direct quotes (verbatim) from the interview results to maintain the authenticity of the informant's voice, before conclusions were drawn that were temporary and continuously verified through source triangulation, technical triangulation, and member checking. To maintain the validity (trustworthiness) of the data, this study referred to the criteria of credibility, transferability, dependability, and certainty, which were maintained through triangulation, member checking, thick descriptions, and an audit trail of the entire research process (Lincoln & Guba, 1985).

4. RESULTS

The results of the study show three main themes that are interrelated in forming a unified learning experience for elementary school students through immersive Virtual Reality as a STEAM learning medium, namely (1) the experience of using immersive VR as a learning medium, (2) the experience of exploration, interaction, and solving STEAM problems, and (3) the experience of numeracy literacy in solving contextual problems.

Student Learning Experiences in Using Immersive Virtual Reality

Based on interviews with 10 informants, students' learning experiences developed through four main interrelated patterns: initial interest, immersion in the virtual environment, free exploration, and adaptation to the technology. Students' initial interest was evident in the emotional responses they experienced upon first using the device, as expressed by one of the informants below.

"I felt really drawn in because it felt like I was entering a gaming world, even though I was a little confused at first about how to use the device." (R1, interview)

A similar statement was also shown by R5 who stated that he was very enthusiastic because he could see objects as if they were right in front of his eyes. In addition to interest, the experience of immersion was also a characteristic found, namely the feeling of being psychologically present in the virtual environment even though the students were physically in the classroom, as conveyed by R1 who "felt like they were really in that place" and R10 who "felt like they were in the object being studied." The third pattern that emerged was free exploration, namely the tendency of students to actively explore the virtual environment without always waiting for teacher instructions.

"I was curious and wanted to try all the objects in the virtual environment." (R7, interview)

A similar trend was demonstrated by R3, who initially felt apprehensive but then became more comfortable after trying it. However, not all students' experiences were positive. Some students experienced technical difficulties and physical discomfort while using the device, such as R6, who initially struggled to control the device, and R4, who expressed the following:

"I felt happy, but I did get a bit dizzy when I used VR for too long." (R4, interview)

A summary of the frequency of code occurrence in this sub-theme is presented in Table 1.

Table 1. Frequency of Immersive VR Usage Experience Codes

Code	Frequency (from 10 Informants)
Exploration	10
Immersion	9
Enthusiastic	9
Technical difficulties	7

The code "exploration" appeared in all informants, followed by "immersion" and "enthusiasm" which each appeared in 9 informants, while "technical difficulties" remained in 7 informants, indicating that technical barriers are an integral part of the immersive VR-based learning experience at the elementary school level. Variations in the speed of adaptation between informants were also seen: some students were able to adapt quickly and immediately showed high engagement from the first session, while others required a longer adjustment period before feeling comfortable using the device.

STEAM Exploration, Interaction, and Problem-Solving Experiences

Interview data shows that students don't just use immersive VR to observe objects, but also utilize it as a space for active investigation and problem-solving through exploration, information identification, interaction with objects, discussion or collaboration, problem-solving strategies, and solution evaluation. Various exploration strategies emerged from informants' responses, such as R1, who "walked around looking at objects from various directions," and R10, who demonstrated a more collaborative exploration pattern.

"I explore the environment with friends and we discuss while looking for the objects we need." (R10, interview)

In problem-solving strategies, variations in approaches were found among students. R3, for example, chose the strategy of trying independently, making mistakes, and then trying again.

"I try it myself first, if it's wrong I try again until the answer matches the existing object." (R3, interview)

Collaboration aspects also stood out, as demonstrated by R10: "Discussions allowed us to divide tasks, with one person observing the object and the other recording the results" (R10, interview). A summary of the code frequencies for this subtheme is presented in Table 2.

Table 2. Frequency of STEAM Exploration, Interaction, and Problem-Solving Codes

Code	Frequency (from 10 Informants)
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Object exploration	10
Solution to problem	10
Interaction	9
Discussion	8
Collaboration	8

The codes “object exploration” and “problem solving” appeared in all 10 informants, confirming that these two aspects are at the core of students’ STEAM experiences, while the codes “interaction,” “discussion,” and “collaboration” appeared consistently in the majority of informants, showing that social processes play an important role in immersive VR-based learning, not just individual processes.

Student Numeracy Literacy Experience

Research data shows that students experience the numeracy process through the stages of identifying numerical information, measuring and calculating, comparing, contextualizing problems, making decisions, and evaluating answers. In the initial stage, students demonstrated the ability to recognize and use numerical or measurement information in virtual objects, for example, R1 who "counted the number of object parts" and R5 who "used length and width information" to understand the observed object, while R9 has applied multiplication operations in completing his task. The contextual aspect of numeracy literacy also appears strong. Almost all informants were able to connect numeracy activities in the virtual environment with everyday life situations, as conveyed by R5 below.

“Calculating materials in a virtual environment is similar to calculating materials when making something in everyday life.” (R5, interview)

The results of the students' calculations were also used as a basis for decision-making, as expressed by R10: "Once we know the amount of material needed, we can determine whether the available material is sufficient to complete the object" (R10, interview). Field notes also supported this finding, for example when a student said, "If one part is 20 cm long, then all of them..." before returning to observe the virtual object to confirm the number of parts that have similar dimensions (Field Note 3), which illustrates the process of numerical reasoning that occurs naturally and contextually.

Table 3. Frequency of Numeracy Literacy Codes

Code	Frequency (from 10 Informants)
Count	10
Using size	9
Contextual calculation	9
Evaluation of answers	7

The code “calculating” appeared in all 10 informants, followed by “using measurements” and “contextual calculations” which each appeared in 9 informants, while “evaluating answers” although having the lowest frequency (7 out of 10 informants) still indicates that some students have developed an awareness of re-checking the correctness of their calculation results. Overall, the three sub-themes show a close relationship: interest, immersion, and initial exploration become entry points that build student motivation and engagement; this motivation is then realized in STEAM exploration, interaction,

and problem-solving activities; and this process specifically involves students' numeracy literacy skills in solving contextual problems.

5. DISCUSSION

The initial interest and immersion experiences reported by almost all informants align with the concept of place illusion, which is the illusion of being there generated by a virtual environment even though the user consciously knows that the place is not real (Slater, 2018). This finding also reinforces the idea that immersive interfaces can increase engagement and learning by providing multiple perspectives, learning that is situated in a real context, and ease of transfer of knowledge to new situations (Dede, 2009), so that the immersion experienced by students in this study is not just an entertainment sensation, but a psychological mechanism that theoretically contributes to the quality of learning.

However, the high level of student enthusiasm during the initial sessions should be interpreted with caution, given the novelty effect phenomenon. A systematic review of VR-based learning motivation studies found that increases in student motivation frequently occur following VR interventions, but longitudinal study designs are limited, making it impossible to fully separate the contribution of the pure novelty effect from the actual learning effect (Jiang & Fryer, 2024). Similarly, the novelty effect tends to decrease with increasing student exposure to VR technology, and initial tutorials can help students navigate the adaptation phase more quickly (Miguel-Alonso et al., 2024). Therefore, the pattern of "initial interest" followed by "adaptation to the technology" in these findings aligns with the novelty effect pattern.

The technical difficulties and dizziness experienced by some students are consistent with the issue of cybersickness, a significant concern in the educational VR literature. A systematic review of the use of head-mounted displays in educational contexts found that oculomotor disturbances and disorientation were the most frequently reported side effects, making it important for educators to limit session duration and monitor students' well-being regularly (Cossio et al., 2025). There is also a relationship between cognitive load, sense of presence, and cybersickness, which mutually influence the quality of the learning experience in immersive environments (Breves & Stein, 2023). Therefore, the higher the cognitive demands of a VR learning task, the greater the potential for physical discomfort, particularly in elementary school-aged children whose visual perceptual systems are still developing.

Students' tendency to observe, rotate, enlarge, and compare virtual objects can be explained through the perspective of embodied cognition, which is a thinking process that involves direct bodily experience, not just abstract representations in the mind (Liu & Wang, 2025). Manipulating objects physically or semi-physically can help students build a stronger spatial and numerical understanding compared to learning based on static representations such as images in textbooks (Bujak et al., 2013), so that students' behavior of actively observing the size of objects from various directions before calculating indicates that the embodied process also becomes the foundation for students' numeracy abilities.

The tendency of some students to explore and seek information independently before seeking teacher assistance can be interpreted through the lens of situated cognition theory, which states that knowledge is situational and formed through authentic activities in specific contexts (Brown et al., 1989), so that immersive VR in this study functions like an authentic practice space that facilitates students to learn to solve problems through direct involvement. The collaboration and discussion patterns that emerged in most informants strengthen the relevance of the zone of proximal development theory, because cooperative learning allows students to achieve a higher level of understanding through peer assistance (peer scaffolding) compared to individual learning (Clapper, 2015). The learning independence demonstrated by some informants is also relevant to the concept of self-directed learning,

because the use of appropriate technology can increase learning independence, student engagement, and academic achievement simultaneously (Rashid & Asghar, 2016).

The trial-and-error-again problem-solving strategy can be understood through experiential learning theory, which asserts that effective learning occurs through a cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation (Morris, 2020). The immersive VR environment in this study allows for this cycle to occur safely and repeatedly, as students can try out various possible solutions without the risk of permanent errors as in real-life situations.

In terms of numeracy literacy, students' ability to connect numeracy activities in virtual environments with everyday life contexts is highly relevant to the principle of Realistic Mathematics Education, which emphasizes that mathematics learning should begin with meaningful contextual problems, rather than abstract concepts detached from real-life experiences (Gravemeijer & Doorman, 1999). Immersive VR successfully presents this context visually and situationally, so that students do not only calculate mechanically, but also understand why and in what situations a mathematical operation is used.

The sequence of numeracy processes found, from identifying numerical information to evaluating answers, aligns with the numeracy literacy framework in international assessments, which defines mathematical literacy as an individual's capacity to reason mathematically and formulate, apply, and interpret mathematics in various contexts, not merely mastery of arithmetic procedures (OECD, 2023). Numeracy also encompasses the ability to use mathematical information to manage the demands of real-life situations (Gal & Tout, 2014), as evidenced by students' ability to determine the adequacy of materials based on calculation results. This framework aligns with the spirit of the Minimum Competency Assessment, which places contextual reasoning as the core of students' numeracy competencies in Indonesia (Ministry of Education, Culture, Research, and Technology, 2021). Therefore, these findings provide empirical evidence that immersive VR can be a vehicle for developing these competencies starting in elementary school.

These findings also align with the results of an international qualitative study of the experiences of 10–12-year-old elementary school students in Finland, which found that students' experiences with immersive VR were largely positive and resulted in tangible physical, cognitive, and emotional affordances realized during learning (Laine et al., 2023). This alignment—in terms of interest, immersion, active engagement, and technical challenges—strengthens the belief that the patterns of immersive VR-based learning experiences among elementary school students in Indonesia are consistent with findings in elementary education contexts in other countries.

Overall, the three themes discussed demonstrate mutually reinforcing theoretical links: immersion experiences and initial interest serve as psychological prerequisites for the emergence of active engagement in STEAM exploration and problem-solving, which in turn serves as a vehicle for the development of contextual numeracy literacy. However, the findings regarding technical difficulties, novelty effects, and potential cybersickness serve as important reminders that the implementation of immersive VR in STEAM learning in elementary schools needs to be carefully designed, taking into account the duration of use, teacher support, and students' technical readiness, so that the pedagogical benefits offered can be optimized without sacrificing student comfort and learning safety.

6. CONCLUSION

Overall, immersive Virtual Reality as a STEAM learning medium provides an immersive, exploratory, collaborative, and contextual learning experience, which collectively contributes to strengthening elementary school students' numeracy literacy. These findings imply the importance of individual mentoring in the early stages of IVR use, designing activities that do not solely rely on the

novelty effect of the technology, and attention to the duration and ergonomics of device use. Further research with longitudinal or mixed-methods designs across a wider range of informants and locations is needed to more measurably measure the impact of immersive VR on elementary school students' numeracy literacy achievements.

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