

# Exploring the Impact of Metaverse-Based Learning on Elementary Students Spatial Ability, Creativity, and Critical Thinking: A Qualitative Exploratory Study

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**Abstract.** The advancement of educational technology has opened new opportunities for enhancing 21st-century skills among elementary students. One such innovation is the use of Metaverse for Kids, a virtual learning environment that immerses students in interactive and engaging educational experiences. This study aims to explore the impact of metaverse-based learning on students' spatial ability, creativity, and critical thinking. Using a qualitative exploratory approach, data were collected through in-depth interviews, participatory observation, and documentation. The participants were fifth-grade students from three elementary schools who had participated in metaverse-based learning sessions. The findings reveal that Metaverse for Kids positively influences students' spatial reasoning, encourages creative expression, and stimulates critical thinking. The immersive learning experience allows students to visualize abstract concepts, experiment freely, and engage in reflective thinking. The study recommends integrating virtual-based thematic curricula to foster high-order thinking skills among elementary learners.

**Keywords:** Metaverse for Kids, Spatial Ability, Creativity, Critical Thinking, Elementary Education

## 1 Introduction

Education in the 21st century demands learning environments that not only deliver knowledge but also cultivate essential skills such as spatial reasoning, creativity, and critical thinking. These abilities are recognized as part of the core competencies required to navigate complex real-world

problems and dynamic professional environments [1]. Consequently, educators and researchers are seeking innovative tools and methods to build these competencies at an early stage of education, particularly in elementary school.

The emergence of advanced technologies such as virtual reality (VR) and the metaverse provides promising avenues to transform how students learn and engage with content. The metaverse, in particular, offers a simulated, interactive, and often collaborative digital environment that enables learners to experience and construct knowledge in a more meaningful way [2]. In educational contexts, the metaverse supports experiential learning and strengthens conceptual understanding, especially when dealing with abstract and spatially complex subjects [3].

One area that benefits greatly from digital simulations is spatial ability development. Spatial reasoning is the mental capacity to visualize, manipulate, and understand spatial relationships among objects, a skill crucial in mathematics, geometry, and science [4]. Piaget suggested that spatial thinking in children evolves through stages, progressing from egocentric perception to coordinated spatial operations as they interact with their surroundings [5]. Battista also emphasizes the role of visual-spatial tasks in enhancing students' ability to comprehend geometric concepts [6]. Integrating three-dimensional models into learning activities can therefore accelerate this development.

Moreover, virtual environments stimulate multisensory engagement, which is known to strengthen memory retention and conceptual understanding. According to Johnson-Glenberg [3], embodied interaction in virtual reality allows learners to link movement with meaning, thus reinforcing cognitive processing in spatial domains. For elementary students, such experiences are especially valuable as they support developmental needs for concrete and exploratory learning.

In addition to spatial skills, creativity and critical thinking are two interrelated cognitive capacities that are highly valued in modern education. Creativity involves the ability to generate novel and meaningful ideas, while critical thinking entails the capacity to evaluate, reflect, and reason logically [7]. These skills can be enhanced through problem-based and inquiry-driven learning approaches, both of which are supported effectively in a metaverse environment. Digital platforms offer students the freedom to explore diverse solutions, collaborate with peers, and engage in tasks that require decision-making and innovation [8].

Social interaction also plays a vital role in developing these higher-order skills. Vygotsky's sociocultural theory highlights the importance of collaborative learning in the development of cognition. The metaverse enables students to co-construct knowledge in shared virtual spaces, providing opportunities for peer interaction, negotiation of meaning, and social reasoning, which are critical components of creativity and critical thinking.

Despite its pedagogical potential, the actual impact of metaverse-based learning environments on elementary students remains underexplored, particularly in developing educational contexts. While research in higher education has documented benefits of digital immersive learning, studies focusing on young learners in primary settings are still limited. There is a need to understand how children engage with metaverse technology cognitively and affectively.

This study seeks to address that gap by examining how the use of Metaverse for Kids influences the development of spatial ability, creativity, and critical thinking among fifth-grade students.

It also aims to provide an in-depth understanding of students' learning experiences within virtual environments.

## **2 Method**

This qualitative exploratory study was carried out in three public elementary schools that had recently adopted Metaverse for Kids for mathematics instruction. One hundred fifth-grade students participated in the programme, and fifteen were purposively selected as key informants to capture a rich variation of engagement levels. Data were gathered through semi-structured interviews with pupils and teachers, classroom observations during metaverse sessions, and document review of learners' digital artefacts and reflection journals. All interviews were audio-recorded and transcribed verbatim, while observational notes focused on behavioural indicators of spatial reasoning, creativity, and critical thinking. A thematic-analysis procedure followed: transcripts and field notes were repeatedly read, initial codes were generated, and related codes were clustered into three overarching themes: spatial reasoning, creative expression, and critical-thinking development. Constant comparison across data sources ensured consistency, and credibility was strengthened through triangulation of techniques, member checking with participants, and peer debriefing among the research team.

## **3 Findings and Discussion**

### **3.1 Enhanced Spatial Reasoning**

Observation records across the three schools consistently showed that students quickly grasped three-dimensional relationships when manipulating virtual objects in the metaverse. During one session, for example, students were tasked with rotating composite 3D solids to identify the number of visible faces from different angles. Several students, particularly those from School B, were able to identify hidden edges and interior angles of a prism when rotated, a task many had struggled with using textbook diagrams. This suggests an improvement in their mental rotation and spatial visualization skills. A teacher from School A noted, "Usually, they can't tell which face is at the back unless I show a model. But now, they just twist the object on their screen and tell me immediately." This aligns with Newcombe's assertion that interactive spatial tasks build foundational geometry comprehension [4].

Interview data further confirmed this trend. More than half of the informants (9 out of 15) could explain geometric transformations using accurate mathematical terms, such as reflected along the y-axis or translated upward by two units. Prior to the metaverse intervention, most students used vague descriptors like "moved to the side" or "flipped." This shift in language and precision echoes Piaget's theory that spatial understanding evolves through active manipulation and engagement with structured environments [5].

Teachers from all three schools observed a decline in spatial misconceptions after the sessions. Misidentification of angles and confusion between symmetrical and asymmetrical shapes reduced significantly. As one mathematics teacher reported, "When I asked them to draw the net of a cube, almost everyone got it right. That usually only happens after weeks of practice." This supports Battista's [6] claim that sustained visual-spatial activity can enhance geometric reasoning in ways that traditional 2D instruction cannot replicate.

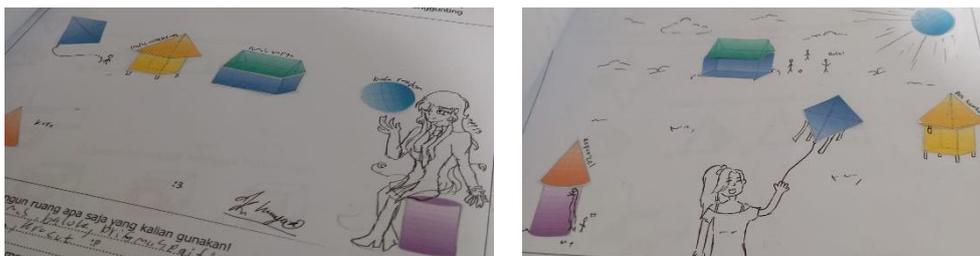
The embodied element of the metaverse appeared to play a crucial role. The platform required students to move avatars, drag and rotate shapes, and simulate walking through virtual spaces, engagements that grounded spatial learning in bodily experience. According to Johnson-Glenberg [3], such embodied cognition, where movement enhances meaning, helps anchor spatial concepts in long-term memory. In one observed session, students “walked through” a model city and used landmarks to discuss coordinate positions. One student said, “I remember where the tower is because I turned left from the bridge and it was right there.” This type of embodied spatial mapping is rarely accessible in traditional instruction.

Notably, the social nature of the metaverse also enriched spatial reasoning. Students often worked in pairs or small groups, rotating objects together and predicting outcomes before applying changes. This encouraged metacognitive reflection and dialogic reasoning. In one activity, a student exclaimed, “If we flip it over this side, the square face will be on top, right?”—to which another replied, “No, it will be the rectangle. Try it!” Such peer-to-peer clarification supports Vygotsky’s theory that learning is mediated through social interaction [9].

Collectively, these findings suggest that Metaverse for Kids acts as a powerful catalyst for the development of spatial reasoning. By combining direct object manipulation, multisensory engagement, embodied interaction, and collaborative discourse, the platform meets diverse learning needs and reinforces abstract geometric concepts in a meaningful way.

### 3.2 Emergence of Creativity

Students' creative abilities became highly visible during tasks requiring them to design houses using basic three-dimensional shapes such as cubes, cuboids, cylinders, cones, pyramids, and spheres. The drawings and models produced by fifth-grade students reflected not only structural creativity, but also a strong connection to their tropical surroundings and daily experiences. For instance, several students created houses with triangular prism roofs, cylindrical chimneys, and cone-shaped towers. One student even drew a balloon made of a sphere and imagined themselves holding it during a sunny day, placing this visual detail beside their house drawing. Another built a small yellow house on stilts with a blue prism roof and labeled it as “*rumahku nyaman* (home sweet home).” (see figure 1-2)



**Figure 1-2.** Example of student-designed houses using basic 3D geometric shapes.

This hands-on task encouraged divergent thinking, as students combined standard geometric shapes in novel ways. Reflection statements such as “*rumah yang ada di pikiran saya*” (“the house that I have in my mind”) suggest the presence of self-driven imaginative design. Students often placed additional elements such as a ball to play with, a fireplace for warmth or food preparation, or a veranda to relax and view the sun, indicating their desire to design not only functional but emotionally resonant spaces. These features go beyond replication and illustrate a genuine ownership of the creative process [7].

The flexibility of cutting and pasting shapes from pre-printed sheets allowed students to try different combinations without fear of making permanent mistakes. In some cases, students revised their layout mid-way, switching the cone from the roof to a decorative lantern, or changing the base from a cube to a cylinder. This behavior embodies what Resnick [8] calls “creative tinkering,” in which iterative experimentation fosters imagination. A few students added written labels like “bola ronda” or “*atap rumahku*” to clarify the function of shapes they had arranged, demonstrating thoughtful spatial reasoning alongside creativity (“bola ronda” = neighborhood patrol ball / community watch ball; “atap rumahku” = my house’s roof).

Collaborative settings enriched the design process further. Students often observed each other’s work and borrowed ideas across tables. In several instances, they offered suggestions like, “*Kasih bola aja biar bisa main di depan rumah* (Just add a ball so they can play in front of the house),” or “*Pakai limas buat atap, kayak rumah nenek* (Use a pyramid for the roof, like grandma’s house).” These exchanges align with Vygotsky’s theory [9] that creativity is often co-constructed through dialogue and social interaction, especially in learning communities that value expression over accuracy.

Importantly, teachers noted that even students who typically struggled with drawing or academic writing displayed a high level of confidence and engagement in this task. The use of colorful geometric cutouts and the open-ended nature of the design challenge lowered the entry barrier, allowing all students to participate equally. One teacher remarked, “*Anak-anak yang biasanya pasif justru sangat semangat membuat rumah dengan bentuk unik. Ada yang menambahkan limas sebagai menara, ada juga yang bikin rumah dua lantai dari balok dan kubus* (Children who are usually passive were actually very enthusiastic about making houses with unique shapes. Some added a pyramid as a tower, others made two-story houses using rectangular prisms and cubes).” This supports the assertion that digital or semi-digital media can democratize access to creative tasks [2], [3].

In contrast to traditional model-building with physical materials, this activity allowed for faster revisions, more playful exploration, and integration of personal memories like the presence of a backyard for playing ball or a resting area under the sun. These additions reflect lived experiences in a tropical climate, where outdoor spaces, bright light, and warmth are part of everyday life. One student’s drawing included a sun, clouds, and grass, showing an understanding of not only architectural but also environmental design.

In summary, the students’ creative output through paper-based metaverse simulations using geometric forms demonstrated their ability to express imagination, emotion, and local culture in meaningful ways. Despite working within a constrained set of shapes, they produced diverse house models that were rich in symbolism and relevance. Metaverse for Kids, even when simplified to printable components, successfully provided a scaffold for recursive, student-centered creative expression that is culturally grounded and developmentally appropriate.

### **3.3 Growth in Critical Thinking**

The development of critical thinking among students was most apparent during open-ended challenges in the metaverse-based sessions. In one task, students were asked to design a virtual house using only selected geometric shapes while ensuring the structure was “safe, comfortable, and usable during both sunny and rainy days.” This scenario encouraged them to compare shape stability, discuss rooftop angles, and decide the best base for balance. For instance, in one group, a student argued that a pyramid was “not good for the floor because it’s too pointy,” leading to

a shift toward using a cuboid for the base instead. These choices reflect Facione's critical-thinking elements of analysis, inference, and justification [7].

Observation notes recorded an increased frequency of clarifying questions such as: "*Kalau kerucut jadi atap, nanti hujannya mengalir ke mana?* (If a cone is used as a roof, where will the rainwater flow?)" and "*Kalau rumahnya pakai bola, bisa berdiri enggak?* (If the house uses a sphere, can it stand upright?)" These student-initiated inquiries mark a move toward metacognitive awareness, indicating that students were not just completing tasks, but actively evaluating them. Compared to previous geometry lessons with textbook problems, this activity stimulated more peer-to-peer questioning, prompting collaborative reasoning rather than passive reception.

Post-activity interviews further revealed how the digital environment allowed students to test and revise their hypotheses instantly. One student shared, "*Tadi aku pakai limas buat lantai, tapi nggak cocok, aku ganti jadi balok, terus baru bikin atap* (Earlier I used a pyramid for the floor, but it didn't work, so I changed it to a rectangular prism, and then made the roof)." This process mirrors the inquiry-based model described by Dede [2], where learners engage in cycles of assumption, experimentation, and adaptation within immersive settings. Instead of waiting for teacher feedback, students used visual feedback from the virtual environment to guide their decisions.

Teachers noted a distinct shift in classroom discourse from fact recall to evidence-based reasoning. During group reflections, students were asked to explain their design choices. In several cases, they justified their selections using cause-effect reasoning, such as: "*Aku pilih bentuk balok biar lantainya rata, terus baru bisa ditaruh bola buat main di depan rumah* (chose a rectangular prism so the floor would be flat, and then a ball could be placed there to play in front of the house)." These explanations went beyond simple description and included rationale, supporting Johnson-Glenberg's [3] assertion that immersive learning spaces scaffold deeper levels of argumentation.

Furthermore, in contrast to earlier classroom debates where students lacked visual aids, the metaverse simulations acted as shared reference points that grounded discussion. Students could point to their models and refer to specific parts—"Di bagian sini kan hujan masuk kalau pakai limas, tapi kalau kerucut bisa dialirin ke samping (In this part, rain gets in if we use a pyramid, but with a cone it can be directed to the side)." This anchoring effect reduced cognitive load, as abstract concepts were made visible, and allowed students to focus on evaluating and improving their designs. It also encouraged reflection-in-action, a core aspect of higher-order thinking.

Overall, the Metaverse for Kids environment nurtured a classroom culture where questioning, justification, and critical appraisal became central habits. Even among younger learners, it proved possible to instill the building blocks of critical thinking, not through rote instruction, but through design-based inquiry and socially mediated dialogue rooted in familiar, meaningful tasks.

## 4 Conclusion

This study shows that integrating *Metaverse for Kids* into elementary education has strong potential to enhance students' spatial reasoning, creativity, and critical thinking. Through interactive tasks involving virtual construction using geometric shapes, students demonstrated an improved ability to visualize space, manipulate forms, and reflect on their thinking processes.

Their creations, such as stilt houses with cone-shaped roofs or open porches with recreational features, revealed both imaginative capacity and contextual relevance to tropical settings. Collaborative group work and open-ended challenges also encouraged children to experiment with ideas, express opinions, and evaluate outcomes. The results indicate that even at the elementary level, students can engage meaningfully in higher-order thinking when supported by well-designed digital environments that allow for exploration, dialogue, and revision. These findings support the value of immersive learning tools in promoting key 21st-century competencies in primary education.

## 5 Implications

The results of this study offer several practical implications for educators, instructional designers, and policymakers. First, metaverse-based platforms that support spatial exploration and student-centered design activities can be integrated into mathematics and other subjects to strengthen students' higher-order thinking skills. Teachers may consider incorporating virtual tasks that are open-ended and culturally relevant, such as building tropical-style houses or designing learning spaces that reflect students' local environments. Second, teacher training programs should include components on how to facilitate learning through immersive technologies, focusing on how digital tools can foster creativity, reasoning, and collaboration. Third, school leaders and curriculum developers might explore ways to align immersive experiences with national learning standards, ensuring that these innovations are accessible and pedagogically sound. Finally, further research could investigate the long-term impact of virtual learning environments on student growth across different age levels and content areas.

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