

Mentoring Geography Teachers to Design Metaverse-Based 3D Media for Deep Learning

Adip Wahyudi¹, Evi Fitriana², Slamet Arifin³, Dewa Putra Cisnaulin⁴, Feri Fahrian Maulana⁵

^{1,2,3,4} Universitas Negeri Malang

Jl. Semarang No. 5, Malang, East Java, Indonesia

⁵ Universitas Gadjah Mada

Jl. Teknik Utara, Pogung, Sinduadi, Mlati, Sleman, Yogyakarta, Indonesia

adip.wahyudi.fis@um.ac.id

Abstract. Abstract. Society 5.0 requires teachers to integrate technology into instruction, yet the Batu City Geography Teachers' Working Group (MGMP) struggles to produce interactive, realistic learning materials. This program aimed to strengthen teachers' professional skills in developing Metaverse-based interactive media for deep learning by engaging 16 MGMP teachers in a hybrid mentoring format that combined online instruction with an in-person workshop. Using the Service Learning approach within a qualitative case-study design, data were collected through observation, interviews, reflection sheets, and evaluation of teachers' lithosphere-based 3D media, then analyzed thematically. By the end of mentoring, [isi jumlah] of the 16 teachers had completed and presented an original 3D lithosphere media project, showing concrete gains in ICT design skills and a shift from teacher-centered to collaborative instruction. The 3D space helped visualize abstract phenomena such as mountainous topography and disaster vulnerability, while lightweight web-based tools and small-group role-sharing addressed hardware and connectivity limits.

Keywords: Metaverse, Geography Education, Deep Learning.

1. Introduction

We are currently in a transitional era, moving from the Fourth Industrial Revolution toward Society 5.0. The primary focus of this transition is to prepare for a high-tech society that encompasses all aspects of human life, including the field of education (Arifin *et al.*, 2025). Education 5.0 integrates scientific and technological innovations to create a learning environment that is effective, interactive, and relevant to technological advancements in society (Yusuf *et al.*, 2023). This major shift requires teachers to adapt their classroom teaching methods by utilizing digital media. The metaverse is one alternative that can accelerate the adoption of technology in education effectively and optimally. The metaverse is an interactive virtual world where students can interact and learn together through various materials in an integrated virtual environment (Cahyadi *et al.*, 2023). The strengths of the Metaverse align with the needs of the geography curriculum, which requires extensive use of visualizations in presenting the material (Apriani *et al.*, 2026).

In the context of geography education, the application of Metaverse technology holds tremendous potential, particularly in enhancing the professional skills of geography teachers in presenting spatial concepts such as maps, geographic locations, spatial structures, and geosphere phenomena (Tue & Astin, 2022). Geography teachers must master visual skills because they help them analyze geographic data in greater depth (Podu & Lukum, 2025). Geography instruction in schools still tends to be text-based and limited to the use of two-dimensional images—such as graphics and photographs—to support the presentation of material. It has not yet made optimal use of technology. In fact, the use of interactive digital media can provide a learning experience with

©Authors

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

realistic visualizations, enabling students to understand the material in context (Abdillah et al., 2024). It aligns with the Deep Learning paradigm, in which meaningful learning promotes active exploration, cognitive and emotional engagement, and social interaction among students (Hidayat et al., 2025). Most teachers still lack the skills to develop Metaverse-based learning materials that provide realistic, interactive visualizations and enable students to collaborate within them (Lilik et al., 2024). Earlier tools such as Google Earth illustrate this limitation well: although they provide geospatial context, they remain essentially two-dimensional and therefore cannot fully replicate the immersive, three-dimensional exploration that deep learning requires (Tue & Astin, 2022).

Beyond serving as a visualization tool, the Metaverse breaks down the physical boundaries of the classroom, letting students explore three-dimensional spatial phenomena hands-on rather than through static illustrations, and positioning them as active collaborators rather than passive recipients of information (Ramli et al., 2022). Despite this potential, community engagement and research that combine Metaverse technology, the enhancement of geography teachers' professional skills, and the optimization of deep learning within a single, integrated mentoring model remain scarce a gap this activity seeks to address by working directly with geography teachers in Batu City.

In geography instruction, teachers are required to develop a curriculum that is more relevant to today's digital age (Pratama et al., 2024). However, interviews with teachers who are members of the Batu City Geography Subject Teachers' Association (MGMP) revealed the opposite: there are still many challenges faced in developing geography teaching materials. First, teachers still struggle to create interactive 3D digital teaching materials due to limited design skills and a lack of understanding of immersive technology. Second, time constraints in developing teaching materials limit teachers' opportunities to experiment with new media, leading them to prefer conventional methods. Third, the lack of structured training focused on developing Metaverse-based media results in low teacher confidence. Fourth, teachers tend to rely on monotonous lecture-style methods or static slide presentations, which make the learning environment unengaging and cause students to become passive. Teachers reported that they need direct guidance to design 3D media that reflects local environmental phenomena in Batu City. These findings indicate that partners require support in the form of structured training and guidance to develop Metaverse media capable of integrating visual-spatial aspects, immersive technology, and local geographic context to achieve deep learning.

In the interviews, the teachers also revealed that they found it helpful and were enthusiastic about directly trying out lessons using the Metaverse, as this learning medium is capable of visualizing environments in 3D, thereby not only conveying the material effectively but also providing a new experience in learning geography. The teachers also noted that delivering the material became easier, particularly for topics on geosphere dynamics, which require extensive visualization for each component of the content. Until now, limited field trips have often hindered geography instruction because of cost, accessibility, and safety concerns. The Metaverse offers an effective solution by providing virtual field trips and 3D spatial simulations. Through this technology, students can explore the Earth's surface structure, observe disaster mitigation mechanisms (such as volcanic eruptions or landslide processes), and analyze settlement patterns interactively, all without leaving the classroom. The advantages of the Metaverse are especially relevant and practical for teaching lithosphere dynamics. This topic examines the Earth's physical structure, endogenous processes (such as tectonism, volcanism, and seismic activity), and exogenous processes (such as weathering, erosion, and mass wasting), all of which are dynamic, three-dimensional (3D), and largely occur beneath the Earth's surface. Conventional learning, which relies on two-dimensional (2D) images in textbooks, often struggles to fully represent the mechanisms of subsurface structures or the evolution of landforms. Through the Metaverse, students do not merely view objects passively. However, they can actively participate in a 3D simulation environment to dissect cross-sections of Earth's layers, observe tectonic plate movements and subduction zones, and immersively explore the structure of magma chambers.

These insights are consistent with existing literature: prior studies have shown that using the Metaverse can strengthen teachers' understanding and skills in diversifying instructional media

(Abdillah et al., 2024). while also boosting enthusiasm among both teachers and students (Solissa & Suhaeb, 2026).

In response to these findings, the community service team designed a structured mentoring program as a concrete solution to the limitations geography teachers face in developing immersive learning media, while accelerating their visual-spatial skills and capacity for deep learning through a contextual, 3D-technology-based approach. Within this program, the Metaverse platform functions as a social mediator, allowing local geographic phenomena in Batu City such as its mountainous landscape, geotourism potential, and landslide-mitigation scenarios to be presented in a concrete, interactive, and collaborative way.

Based on the analysis presented, the researchers formulated a solution in the form of a community service program titled “Enhancing the Professional Skills of Geography Teachers through Mentoring in the Development of Metaverse-Based Interactive Virtual Media to Optimize Deep Learning.” This activity addressed teachers’ limitations in developing interactive media and aimed to accelerate the development of visual-spatial skills in deep learning through a contextual approach based on 3D technology. The program was implemented through the PKM (Student Creativity Program) using a “Service Learning” approach that integrates academic experience with the real needs of the teaching community, and was evaluated using a qualitative, case-study-based approach. The event was conducted in a hybrid format on July 6–7, 2026, with 16 teachers from the Batu City Geography Teachers’ Working Group (MGMP). On the first day, July 6, 2026, the session was held online via the Google Meet platform to explore the urgency of deep learning, the framework of immersive pedagogy, and an introduction to the basic architecture of the Metaverse platform. On the second day, July 7, 2026, the event was held in person at Batu State High School 1 and featured workshop sessions and intensive hands-on guidance on creating 3D virtual spaces and designing collaborative project-based learning scenarios. The activities began with mapping school assets using the ABCD and CBR approaches, followed by training and guidance on creating Metaverse media based on lithosphere content. Teachers’ skill development was assessed through participatory observation, media portfolio evaluation, interviews, and critical reflection, and then analyzed using a descriptive thematic approach. Following implementation, a joint evaluation was conducted to formulate recommendations for sustainability, with the goals of enhancing teachers’ 3D ICT competencies, producing Metaverse media, guiding students’ deep learning, and strengthening collaboration among universities, partner schools, and the Batu City Geography Teachers’ Working Group (MGMP). This activity therefore aimed to strengthen the professional and ICT competencies of Batu City’s geography teachers by mentoring them in designing Metaverse-based 3D media on lithosphere topics of foster deep learning among their students.

2. Method

This community service project applies the concept of Service Learning using a descriptive qualitative approach oriented toward case studies. The implementation of Service Learning fosters students’ theoretical understanding and practical field experience. Students collaborate with geography teachers in develop Metaverse educational media and provide students with a deep learning experience. Through qualitative analysis, the community service team conducted an in-depth exploration of how of enhance teacher competencies, design of 3D virtual spaces, and assess the effectiveness of these tools as social mediators in collaborative learning. This PKM activity was conducted in a hybrid format over two days on July 6–7, 2026. On the first day, July 6, 2026, the event was held online via Google Meet, with an emphasis on reinforcing deep learning theory and pedagogy, as well as an introduction to the Metaverse platform. The second day, July 7, 2026, was held in person through a hands-on workshop on creating 3D learning media in the auditorium of Batu State High School No. 1. Batu State High School No. 1 was selected as the host location due to its facilities, which are well-suited to support training needs, as well as its status as one of the leading schools in the city of Batu.

The main participants in this activity were 16 geography teachers who are members of the Batu City Geography Teachers’ Working Group (MGMP), selected through purposive sampling.

The purposive selection was based on criteria including active involvement in MGMP community activities, readiness to integrate ICT into teaching, and a genuine need for innovative spatial-based learning media. Students were fully involved in all stages, from initial planning and fieldwork to the evaluation session. At the outset, students received training in Asset-Based Community Development (ABCD) and Community-Based Research (CBR) methods to equip them before deployment. Through this training, the students learned to assess the availability of school assets and the personalities of the teachers, ensuring that the mentoring they provided was firmly grounded in on-the-ground realities. For context, the Batu City Geography Teachers' Working Group (MGMP) has a total of about 30 active members. Therefore, the 16 participating teachers constitute a purposively selected subgroup of this broader population, not the entire MGMP membership.

All community service activities were divided into pre-implementation, implementation, and post-implementation phases. In the initial phase, the PKM team, together with faculty members, observed the challenges faced by geography teachers in Batu City, particularly the difficulty of presenting lithosphere material without 3D media that supports deep learning. The team then mapped the schools' potential and teacher profiles using the ABCD and CBR frameworks. Based on these findings, the team developed a practical module for designing the Metaverse to support deep learning on lithosphere-related topics, such as the Earth's layers, types of rocks, and mountainous landscapes. This guide enables teachers to design 3D virtual spaces for student collaboration, fostering deeper understanding of the material (deep learning).

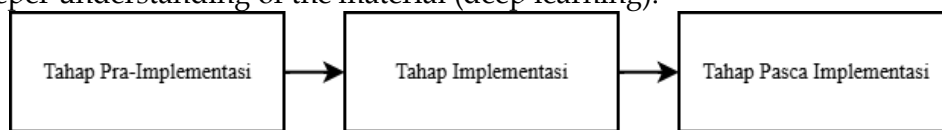


Figure 1. Activity Stages

The implementation phase involved intensive training and mentoring for geography teachers who are members of the Batu City Geography Teachers' Working Group (MGMP). Teachers were supported in designing, developing, and utilizing Metaverse-based 3D virtual environments, such as a 3D lithosphere museum and the topography of Andongrejo. The observation and evaluation instruments for this phase were developed based on the indicators of teachers' professional competencies as outlined by (Prasetya et al., 2026). These include understanding geography content, developing lesson plans, creating innovative teaching materials, mastering ICT, and the practice of self-improvement through reflection. Data collection included participatory observation during workshops, interviews, reflective journals, and an examination of participants' 3D media projects. The analysis followed a thematic framework, from data reduction and presentation to conclusions, in order to map patterns of improvement in teachers' competencies and the role of the Metaverse in fostering student interaction. Concretely, data collection relied on four instruments: an observation checklist tracking each teacher's engagement during hands-on sessions, a semi-structured interview guide, an open-ended reflection sheet completed after each session, and a product assessment rubric evaluating the completeness, spatial accuracy, and interactivity of the resulting 3D media, detailed in Table 1 below. Members of the research team conducted qualitative data analysis; they cross-checked codes and resolved disagreements through discussion to minimize individual bias and improve the consistency of the analysis.

Table 1. Instrument Blueprint

Instrument	Competency Indicator(s) Targeted	Aspects / Sample Items
Participatory observation checklist	Mastery of ICT; creation of innovative teaching materials	Engagement during hands-on sessions; fluency navigating the Metaverse platform (movement, asset placement, object manipulation); initiative in

		customizing the 3D template beyond guided instructions
Semi-structured interview guide	Understanding of geography content; development of lesson plans	Teacher's conceptual grasp of the lithosphere material being visualized; plans for integrating the 3D media into lesson plans or teaching scenarios; perceived challenges and coping strategies
Open-ended reflection sheet	Practice of self-improvement through reflection	New skills or insights gained after each session; personal difficulties encountered and how they were addressed; follow-up plans for classroom implementation
Product assessment rubric	Creation of innovative teaching materials; mastery of ICT	Completeness (coverage of the intended lithosphere content); spatial accuracy (proportion and placement of 3D objects); interactivity (presence of elements students can explore or click)

The post-implementation phase focused on a joint reflection session involving university faculty, students, and teachers from the Batu City Geography Teachers' Working Group (MGMP). This meeting was used to evaluate the program's achievements, assess the extent to which the 3D virtual space Metaverse can help students engage in deeper learning, and identify the technical and instructional challenges that teachers encountered. Notes from this session served as the primary basis for formulating recommendations for the development of future educational media to ensure they remain relevant for use in schools, while also maintaining collaborative relationships between the university, schools, and the MGMP. To collect data, the team relied on direct observations during mentoring sessions, reflection sheets, in-depth interviews, and reviews of draft learning scenarios and 3D products created by teachers. These steps ensured that the improvement of teachers' skills and the implementation of the Metaverse in the classroom could be fully mapped.

Data analysis used qualitative thematic analysis. All data – from participatory observations, reflection sheets, in-depth interviews, to the teachers' Metaverse creations – were examined through the stages of data reduction, data presentation, and conclusion. This approach helped identify key themes, including how teachers adopted Metaverse technology, the effectiveness of 3D spaces as a medium for learning interactions, technical and pedagogical barriers, and patterns of competency development among geography teachers. This provided a clear picture of the contributions of the mentoring activities, particularly regarding mastery of spatial content, visualization of lithosphere-related material, and the collaborative use of ICT. This initiative also strengthens the network among universities, partner schools, and the MGMP to ensure the long-term utilization of technology in schools. To strengthen the trustworthiness of these qualitative findings, the team applied source triangulation by cross-checking observation notes, interview transcripts, and reflection sheets against one another, together with member checking, in which preliminary findings were shared with several participating teachers to verify their accuracy before the analysis was finalized.

3. Result

The mentoring program of develop Metaverse-based Interactive Virtual Media to optimize deep learning was opened by the Chair of the Batu City Geography Teachers' Working Group (MGMP). In the first phase, the training was conducted online via Google Meet and covered the importance of deep learning, the fundamentals of immersive pedagogy, and an overview of the Metaverse digital space. In the second phase, the activities continued in person at Batu State High School 1. Participants took part in training and hands-on guidance to design 3D virtual spaces while developing group-based project learning scenarios. The final phase of the community service project

consisted of evaluation and qualitative data mapping. We analyzed findings from participatory observations, reflection sheets, and in-depth interviews on teachers' Metaverse creations through data reduction, presentation, and conclusion-drawing.

Quantitatively, 16 teachers who participated 100% completed and presented original 3D lithosphere media projects by the end of the mentoring period. In contrast, the other teachers produced partial prototypes that were later completed with additional ongoing guidance.

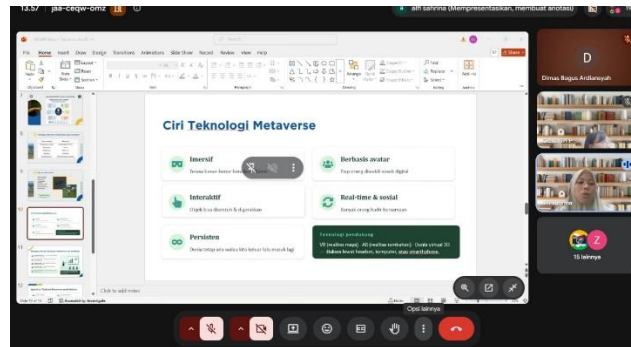


Figure 2. Introduction to the Metaverse via the Google Meet platform – an online session in which teachers were introduced to deep learning pedagogy and the basic architecture of the Metaverse prior to the hands-on workshop.

The results of participatory observations and in-depth interviews conducted during the mentoring activities on July 6-7, 2026, indicate that the introduction of interactive virtual media based on the Metaverse has the potential to transform the mindset of teachers who are members of the Batu City Geography Teachers' Working Group (MGMP). Before the mentoring, most teachers struggled in present abstract spatial geographic phenomena, such as mountainous landforms and the dynamics of disaster vulnerability. The use of 3D virtual spaces allows these spatial concepts to be visualized contextually and interactively. The use of the Metaverse platform not only enhances teachers' technological skills but also shifts the paradigm of instruction from a teacher-centered approach to collaborative learning. As one participant, hereafter referred to as Teacher A (a geography teacher and MGMP member), noted:

"Through the Metaverse, we can help students explore mountainous terrain more realistically. Students no longer look at two-dimensional images in textbooks; instead, they discuss and analyze landslide-prone areas together in a virtual space."



Figure 3. A virtual metaverse environment powered by Spatial.io features a 3D lithosphere that teachers explore to practice spatial navigation and collaborative interaction.

The statement confirms that 3D-based immersive technology significantly enhances teachers' professional competencies, particularly in their ability to creatively develop lesson materials and use ICT for innovative teaching methods (Misbahudholam et al., 2025). Furthermore, these findings reinforce the findings of (Putra et al., 2026) who view technology not merely as a passive visual aid, but as a social mediator that is, a medium that fosters communication, social interaction, and the

construction of shared knowledge among students in a virtual space. Support for the continued adoption of this technology was also emphasized by the leadership of the Batu City Geography Teachers' Working Group (MGMP), represented here by the MGMP Chairperson:

"This guidance provides a new direction for the MGMP. Teachers usually only use presentation tools like PowerPoint, but the Metaverse creates a new experience in geography education."

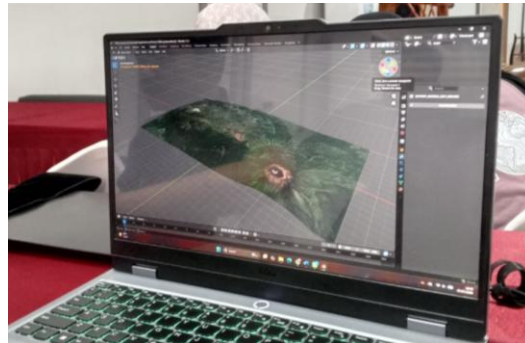


Figure 4. The Metaverse Asset Creation Process depicts teachers creating 3D lithosphere assets, such as a 3D lithosphere museum and the topography of Andongrejo, complete with interactive rock type labels, cross-sectional views of subsurface layers, and navigable terrain models, which are evaluated using the product assessment rubric described in the Methods section – namely, completeness, spatial accuracy, and interactivity

Although teachers have experienced significant added value from using the *Metaverse*, the process of adopting immersive technology in schools faces several technical and operational challenges. The main obstacles identified include limitations in the school's hardware specifications for 3D graphics *rendering*, fluctuations in internet connection stability, and varying levels of 3D navigation literacy among teachers. As one teacher, hereafter Teacher B, explained regarding this challenge:

"The Metaverse platform is highly interactive, but our main challenge lies in the inconsistent computer specifications at schools and the sometimes slow internet connection when loading complex 3D objects."

To address these infrastructure limitations, teachers developed various adaptive strategies during hands-on sessions at SMA Negeri 1 Batu. The teachers used lightweight, web-based Metaverse platforms such as Spatial.io or FrameVR and designed one-device, multiple-user scenarios based on role-sharing within small groups.

"We address the limited number of devices by dividing students into working groups. One student acts as the navigator in the 3D space, while the other group members observe the geographic indicators on the worksheet and lead the discussion on mitigation analysis."

This strategy challenges the assumption that the use of advanced technology always leads to individual isolation. Through the design of collaborative, project-based learning scenarios, immersive technology actually serves as an effective tool for fostering social skills, role-sharing, and negotiation in spatial problem-solving among students.



Figure 5. Documentation from the Metaverse Media Training Seminar illustrates the collaborative small-group work format used to address the limited availability of devices.

This social engagement also supports deep learning. Deep learning in education fosters the ongoing development of conceptual understanding, relationships between concepts, critical thinking skills, and the application of these concepts in real life (Rohsulina et al., 2026). Deep learning is defined as a process of deep and meaningful learning that requires students' spatial reasoning and critical thinking skills. This deep learning becomes evident when students go beyond memorizing definitions and instead analyze geographical phenomena through 3D visualizations. In the lithosphere module, students do not merely identify Earth's layers and rock types on paper; instead, they collaborate within the Metaverse to reconstruct tectonic processes, observe volcanic eruptions, and analyze the formation of land contours firsthand. These findings offer a new perspective on concerns regarding the negative impact of technology on student interactions. When paired with appropriate immersive pedagogy, 3D virtual spaces can serve as catalysts for deep learning, strengthening students' understanding holistically and interactively. In practice, these 3D exercises visibly deepened students' engagement with lithosphere content compared to earlier, less interactive methods. These outcomes also align with several of the five teacher-competency indicators identified by (Prasetya et al., 2026) in the Methods section, most visibly mastery of ICT, the creation of innovative teaching materials, and reflective self-improvement, though the link to lesson-plan development and content mastery would benefit from more direct evidence in future evaluations.

4. Discussion

The results of this study indicate that the integration of Metaverse technology can shift geography learning patterns from a teacher-centered approach to student-centered, collaborative learning. These findings reinforce the view (Maulana et al., 2023) that Metaverse-based learning media can create virtual interaction spaces that significantly enhance student learning outcomes. In line with this, (Diao & Su, 2025) also emphasize that the Metaverse offers a more realistic and collaborative learning experience compared to conventional media, so that teachers no longer serve as the sole source of information but rather as facilitators of students' exploration of knowledge within the virtual space.

The improvement in the professional competence of geography teachers observed in this activity is also consistent with the indicators of teacher professional competence formulated by (Wahyudi et al., 2026), particularly in the areas of subject matter mastery, creativity in developing instructional materials, and mastery of information and communication technology (ICT). Geography teachers in the Batu City MGMP, who were previously limited to using two-dimensional visual media, are now able to design more contextual three-dimensional media, as also reported by (Wahyudi et al., 2025) who noted that the development of digital-based geography learning media can support character building and a deeper conceptual understanding among students. This finding also reinforces the results of a mentoring study (Lai et al., 2025), which showed that intensive Metaverse-based training effectively enhances teachers' capacity to produce innovative learning media. That said, this improvement is best read as an early-stage shift in confidence and willingness to experiment rather than full mastery: unlike the longer, curriculum-embedded intervention reported by (Wahyudi et al., 2025), the present mentoring was delivered over a short, intensive period, so sustained competency gains still need verification through follow-up observation.

The Metaverse's role as a social mediator in this activity reinforces the findings (Gleadow et al., 2015) that digital technology serves not only as a visual aid but also as a medium that fosters social interaction and the construction of shared knowledge among students. This was further confirmed by (Le, 2025), who found that the use of the Metaverse can foster enthusiasm and active engagement among students in the learning process. The results of this mentoring provide additional empirical evidence that the success of immersive technology integration depends not only on the sophistication of the platform's features but also on the design of collaborative learning scenarios that encourage meaningful social interaction, as also emphasized by (Mishra & Nair, 2025) in the context of utilizing other adaptive media based on immersive technology. Unlike (Le, 2025), however, whose setting involved learners with more consistent access to personal devices,

engagement in this activity was mediated by shared devices and role-sharing, suggesting that the enthusiasm observed here is partly a product of the collaborative workaround itself rather than the Metaverse platform alone.

Nevertheless, the challenges posed by limited school infrastructure identified in this study are consistent with the results of a needs analysis (Bantun et al., 2026) which also identified gaps in device specifications as the primary obstacle to the implementation of Virtual Reality-based learning media in schools. Adaptive strategies such as the use of a web-based Metaverse platform and role-playing in small groups developed by teachers from the Batu City Geography Teachers' Working Group (MGMP) demonstrate that technical limitations are not insurmountable barriers but can be addressed through the design of contextual learning scenarios, in line with the idea (Crupie et al., 2025) that the adaptive use of technology is key to meeting the demands of the Society 5.0 era.

The deep learning outcomes observed in this activity – particularly in collaboratively reconstructing tectonic processes and analyzing landform formation – reinforce the deep learning framework proposed by (Pejic et al., 2024) which states that deep learning requires students' spatial reasoning, cognitive-emotional engagement, and critical thinking skills. Compared to the use of Google Earth as a contextual medium for geography learning – which is still limited to two-dimensional visualization (Tong et al., 2025) the Metaverse-based 3D virtual space in this activity offers a more immersive spatial experience, allowing students to understand lithospheric dynamics more comprehensively. These findings also address the identified need (Rosanawati et al., 2025), for information technology-based geography learning that is relevant to the Merdeka Curriculum in the digital age. This is consistent with the broader conceptualization of deep learning as a process that fosters the ongoing development of conceptual understanding, relationships between concepts, and critical thinking, applied meaningfully to real-world problems (Rohsulina et al., 2026).

Overall, the results of this mentoring program address the research gap outlined earlier – namely, the limited number of studies that integrate Metaverse technology, the enhancement of geography teachers' professional skills, and the optimization of deep learning into a single, comprehensive mentoring model. However, this initiative still has limitations, including a relatively small number of participants and a scope limited to a single MGMP region; therefore, generalizing the findings requires caution. Further research and community engagement are recommended to expand the scope of partners and to quantitatively assess the long-term impact of Metaverse implementation on student learning outcomes, thereby strengthening the external validity of the findings. Another limitation relates to participant selection, as teachers were selected through purposive sampling partly based on their existing ICT readiness. These findings likely reflect the experiences of a group that is generally already quite confident with technology and may not be generalizable to teachers who previously had limited exposure to digital devices. To sustain learning beyond the PKM period, schools or education agencies need to provide ongoing mentoring, support, or the formation of MGMP communities of practice to ensure continued use of the Metaverse. Without such mechanisms, the increase in teachers' confidence in ICT documented here risks fading once direct mentoring ends.

5. Conclusion

This Service Learning-based community service program, conducted in collaboration with 16 teachers from the Batu City Geography Teachers' Working Group (MGMP), successfully shifted the learning process to a student-centered approach of using a 3D Metaverse space (Spatial.io) to teach lithosphere dynamics. The team effectively addressed challenges related to hardware specifications and internet connectivity of using a web-based platform and role-sharing strategies within small groups. In addition to enhancing teachers' ICT skills and strengthening partnership networks, this program provided theoretical insights and low-cost practical solutions that teacher communities in other regions can replicate. To ensure the sustainability of these positive impacts, further research is recommended to track the long-term use of this technology with a broader sample, aligned with official policy support from education authorities and school administrators through periodic mentoring.

6. References

- Abdillah, L. A., Azdy, R. A., Ernawati, Y., & Mukti, A. R. (2024). Pengembangan Media Pembelajaran Berbasis Augmented Reality Dan Metaverse Untuk Meningkatkan Kinerja Guru Sma/Smk/Slb Di Provinsi Sumatera Selatan. *Jurnal Hilirisasi IPTEKS*, 7(2), 160-169. <https://doi.org/10.25077/jhi.v7i2.738>
- Apriani, B., Asriati, N., & Adlika, N. M. (2026). Analisis Kebutuhan Pengembangan Media Pembelajaran Virtual Reality Berbasis Millealab Pada Mata Pelajaran Geografi Di Sma Negeri 1 Pontianak. *Jurnal Education and Development*, 14(1), 348-354.
- Arifin, M., Noviyanti, N., & Dedek Berliani. (2025). Model-Model Pembelajaran di Era 5.0 dan Tantangan dalam Implementasi. *DIAJAR: Jurnal Pendidikan Dan Pembelajaran*, 4(3), 418-424. <https://doi.org/10.54259/diajar.v4i3.4436>
- Bantuan, S., Kuswandi, D., Ulfa, S., Praherdhiono, H., Sari, J. Y., & Degeng, M. D. K. (2026). Utilization of augmented reality technology in overcoming educational issues in Indonesia. *Bulletin of Electrical Engineering and Informatics*, 15(4), 3291-3304. <https://doi.org/10.11591/eei.v15i4.10156>
- Cahyadi, M. H., Prasetya, S. P., Prastiyono, H., & Marzuqi, M. I. (2023). Pengembangan Media Pembelajaran Berbasis Metaverse Menggunakan Virtual Reality (VR) Untuk Meningkatkan Hasil Belajar Siswa. 5(4), 109-122.
- Crupie, An., Marinelli, L., & Cacciatore, E. (2025). *The Generative AI Impact: Reframing Innovation in Society 5.0* (A. Crupi, L. Marinelli, & E. Cacciatore, Eds.). Emerald Publishing Limited. <https://doi.org/10.1108/9781835491058>
- Diao, Y., & Su, Y. (2025). Exploring the Impact of the Metaverse on Promoting Students' Access to Quality Education: A. *IEEE Transactions on Learning Technologies*, 18, 321-334. <https://doi.org/10.1109/TLT.2025.3550714>
- Gleadow, R., Honeydew, M., Ford, A., Isaac, B., & Abbott, K. (2015). New tools for a new age: An evolution or revolution in higher education? *F1000Research*, 4, 1-13. <https://doi.org/10.12688/f1000research.7533.1>
- Hidayat, M. A., Agustin, D. T., Hana, N., Ramadhani, R., Pratiwi, D. A., & Aslamian. (2025). Keunggulan Implementasi Kurikulum Merdeka Berbasis Pendekatan Deep Learning di SDN 1 Sungai Besar. *Pendas: Jurnal Ilmiah Pendidikan Dasar*, 10(2), 251-264.
- Lai, W. W., Lopez-Ozieblo, R., Shen, D. J., & Tong, E. K. (2025). *Engaging the Digital Learner: Navigating Learning Landscapes in the Metaverse BT - Perspectives and Trends in Education and Technology* (J. V. Carvalho, A. Abreu, E. Ferreira da Costa, E. Vázquez-Justo, & H. Viguera Figueroa, Eds.; pp. 344-354). Springer Nature Switzerland.
- Le, X. C. (2025). What determines learners' active participation in Metaverse-based learning in an emerging market. *Library Hi Tech*. <https://doi.org/10.1108/LHT-06-2024-0300>
- Lilik, B., M. Anas Thohir, & Dani Irawan. (2024). Mengintegrasikan Teknologi Metaverse dalam Media Pembelajaran: Fokus pada Peningkatan Kapasitas Guru di Sekolah Alam Alghifari Blitar. *Jurnal Abdimas Indonesia*, 4(3), 1428-1439. <https://doi.org/10.53769/jai.v4i3.1045>
- Maulana, F. F., Deffinika, I., Jazilah, F., & Pokhrel, L. B. (2023). Virtual Learning Media Exploration 3D View of the Konto River Watershed to Support 21st Century Learning. *Jambura Geo Education Journal*, 4(2), 133-146. <https://doi.org/10.34312/jgej.v4i2.21399>
- Misbahudholam, M. A., Armadi, A., Puji Astuti, Y., & Astutik, C. (2025). Inovasi Abad 21: Penguatan Kompetensi Guru Dalam Pemanfaatan Media Pembelajaran Adaptif Berbasis Augmented Reality Dengan Bantuan Aplikasi Asemblr Edu Di Era Industri 5.0. *Jurnal Medika: Medika*, 4(3),

612–626.

- Mishra, S., & Nair, S. S. (2025). Infinite Horizons. In *Distributed and Parallel Computing* (pp. 135–151). <https://doi.org/https://doi.org/10.1002/9781394288038.ch7>
- Pejic, J., Petkovic, M., & Klinge, S. (2024). *Exploring spatial reasoning performances of CNN on linear layout dataset OPEN ACCESS Exploring spatial reasoning performances of CNN on linear layout dataset*.
- Podu, R. P., & Lukum, A. (2025). Pengembangan Media Pembelajaran Geografi Berbasis Digital untuk Mendukung Pendidikan Karakter. *Jurnal Penelitian, Pendidikan Dan Pengajaran: JPPP*, 6(2), 129–136. <https://doi.org/10.30596/jppp.v6i2.26883>
- Prasetya, I., Sihotang, R. B., Rahma, B. S. A., Parhusip, G. A., & Marweki, R. A. (2026). Kompetensi Profesional Guru: Konsep, Indikator, Dan Implikasinya Terhadap Mutu Pendidikan. *Pendas : Jurnal Ilmiah Pendidikan Dasar*, 11, 830–840.
- Pratama, A., Fazera, D., Fortunata, L. A., & Fadilah, R. (2024). Analisis Kebutuhan dan Perencanaan Pembelajaran Geografi Berbasis Teknologi Informasi di Era Digital pada Kurikulum Merdeka di SMA Negeri 3 Medan. *ARSEN: Jurnal Penelitian Pendidikan*, 1(2), 93–101. <https://doi.org/10.30822/arsen.v1i2.2974>
- Putra, P., Ilias, M. F., Hartono, R., Burhanuddin, Saputra, N., & Barsihanor. (2026). Digital Literacy as a Transformative Framework for Character Education: A Case Study in Madrasah Ibtidaiyah. *Nazhruna: Jurnal Pendidikan Islam*, 9(1), 33–51. <https://doi.org/10.31538/nzh.v9i1.429>
- Ramli, T. S., Dadang, E., Zamil, Y. S., Muttaqin, Z., Putri, S. A., Cahyadini, A., Ramadayanti, E., Millaudy, R. A., Hidayat, M. J., & Aurellia, B. (2022). Pemanfaatan Teknologi Bagi Siswa Dalam Menyokong Peningkatan Ekonomi Digital Dan Upaya Menghadapi Era Society 5.0. *ACTA DIURNAL Jurnal Ilmu Hukum Kenotariatan Fakultas Hukum Universitas Padjadjaran*, 6, 81–98.
- Rohsulina, P., Wijayanti, A., Rifai, M. H., Rahman, M. K., & Kurniaaji, B. (2026). Integrasi Ekopedagogik Melalui Pendekatan Deep Learning Dalam Pembelajaran Geografi Sekolah Menengah Atas: Studi Multi-Site. *Jurnal Jaringan Penelitian Pengembangan Penerapan Inovasi Pendidikan (Jarlitbang)*, 15–26. <https://doi.org/10.59344/jarlitbang.v12i1.365>
- Rosanawati, I. M. R., Wardo, W., Djono, D., & Purwanta, H. (2025). Pedagogical Model Innovation Based on Ki Hajar Dewantara's Among System for History Learning in the Merdeka Curriculum. *Educational Process: International Journal*, 14. <https://doi.org/10.22521/edupij.2025.14.39>
- Solissa, W. E., & Suhaeb, F. . (2026). Pemanfaatan Metaverse Berbasis Kearifan Lokal: Transformasi Museum Digital Dalam Pembelajaran Ips Smp Di Manokwari. *Jurnal PenKoMi: Kajian Pendidikan Dan Ekonomi*, 9(2), 106–115.
- Tong, F., Liu, X., Wang, Q., & Zhu, K. (2025). Construction and Teaching Model Research of 3D Network Learning Space Based on Metaverse. *2025 7th International Conference on Computer Science and Technologies in Education, CSTE 2025*, 691–696. <https://doi.org/10.1109/CSTE64638.2025.11092016>
- Tue, F., & Astin, L. (2022). Implementasi Google Earth Sebagai Media Pembelajaran Kontekstual Pada Mata Pelajaran Geografi. *Irfani: Jurnal Pendidikan Islam*, 18(November), 126–134.
- Wahyudi, A., Arifin, S., Solikhin, M., Sahrina, A., Maulana, F. F., Roziqin, M. F. A., & Shrestha, M. E. I. (2026). Integration of artificial intelligence technology in learning evaluation using the ADDIE method. *IAES International Journal of Artificial Intelligence*, 15(4), 3068–3080. <https://doi.org/10.11591/ijai.v15.i4.pp3068-3080>
- Wahyudi, A., Deffinika, I., Mutia, T., Maulana, F. F., Maghfiroh, A., Prista, D., & Indraningrum

Shrestha, M. E. (2025). Integration of micro e-learning content in SIPEJAR geodupreneurship course based on real life entrepreneurship. *Jurnal Penelitian Dan Pengembangan Pendidikan*, 9(1), 56–66. <https://doi.org/10.23887/jppp.v9i1.86241>

Yusuf, M., Dwi Julianingsih, & Tarisya Ramadhani. (2023). Transformasi Pendidikan Digital 5.0 melalui Integrasi Inovasi Ilmu Pengetahuan dan Teknologi. *Jurnal MENTARI: Manajemen, Pendidikan Dan Teknologi Informasi*, 2(1), 11–19. <https://doi.org/10.33050/mentari.v2i1.328>