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Transforming Science Learning in the Era of Education 5.0 Through Virtual Reality (VR) Millea Lab: Improving Understanding of Science Concepts and Technological Literacy for Digital Native Students

Ani Anjarwati[1*], Ryzca Siti Qomariyah[1], Dinar Ayu Prameswari[1], Serly Nurul Laili[1], Pepilian Dwi Retno Wahyuningrum[1]

[1] Department of Elementary Education, Faculty of Education, Panca Marga University, East Java, Indonesia.

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Corresponding Author:
Ani Anjarwati
anianjarwati.upm@gmail.com

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Abstract: This study aimed to develop and evaluate MilleaLab Virtual Reality (VR) learning media to support elementary science learning within the framework of Education 5.0. The product was designed using the ADDIE model and validated by both media and content experts, each achieving a feasibility score of 96.67%, surpassing the minimum threshold of 80%. The implementation involved 225 students from Grades IV and V across four elementary schools in East Java. Students learned science topics on green plants and the digestive system through immersive VR-based activities. Effectiveness was measured using pre-test and post-test scores, yielding an overall mean N-Gain of 0.50, which falls into the moderate category. Reflection data collected through a six-item Likert-scale questionnaire showed that more than 60% of students rated the learning experience as very good, while none rated it poor or very poor. These results indicate that MilleaLab VR enhances students' conceptual understanding and provides positive learning experiences. However, the variation in N-Gain across schools highlights the importance of adequate device availability, internet stability, and teacher readiness to optimize VR integration. This study concludes that MilleaLab VR is feasible and moderately effective for transforming science learning in elementary schools, contributing to digital literacy development in the Education 5.0 era.

Keywords: Digital native student; Era education 5.0; Millea lab; Science learning; Virtual Reality (VR)

Introduction

The rapid development of global technology over the past two decades has triggered the emergence of the Fourth Industrial Revolution (Industry 4.0), characterized by the integration of artificial intelligence, big data, the Internet of Things (IoT), and cyber-physical systems across various sectors (Suryadi & Nasution, 2023). This transformation presents both opportunities and challenges for the education sector, which is now moving towards the Education 5.0 paradigm. This paradigm emphasizes humans as the center of learning, supported by smart technologies to foster creativity, innovation, collaboration, and social responsibility. Digital native learners require interactive, contextual, and immersive learning experiences, making conventional methods such as lectures and textbooks no longer adequate (Darwin et al., 2025). Previous studies

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have also highlighted that interactive digital learning media can bridge the gap between curriculum demands and 21st-century learning characteristics (Huljanah & Zai, 2025).

At the elementary school level, mastering scientific concepts remains a significant challenge, even though the Merdeka Curriculum emphasizes core competencies and digital literacy (Mustofiyah et al., 2024). These challenges are influenced by teachers' limited creativity in utilizing digital media (Febriyanti et al., 2021), the dominance of lecture-based teaching (Sari et al., 2025), and the lack of inquiry-based approaches (Laspita, 2024). The abstract nature of scientific concepts, such as human organ systems, food cycles, and ecosystem interactions, further complicates students' understanding (Suharini & Widyatmoko, 2025). Therefore, the use of concrete and interactive media has proven essential in facilitating the comprehension of abstract concepts (Handayani et al., 2022; Rulyansah et al., 2022).

Interactive digital media, such as animations, have been shown to increase students' motivation and engagement in the learning process (Rulyansah et al., 2022). Moreover, the development of three-dimensional visual media provides contextual and engaging learning experiences (Anjarwati, 2018; Anjarwati et al., 2023b), while Montessori-based media help students develop a deeper understanding of science concepts (Anjarwati et al., 2023a). Furthermore, digital-based learning models integrated with quantum learning approaches also support conceptual understanding among digital native students (Anjarwati et al., 2024). These findings align with the learning demands of Society 5.0, which require technology-based education (Warastuti et al., 2025).

One of the most prominent innovations is the use of Virtual Reality (VR) in science learning. This technology enables interactive 3D simulations that allow students to explore abstract concepts as if directly interacting with real phenomena (Reffiane et al., 2025). Studies show that VR can enhance students' motivation, engagement, and conceptual understanding (Mufit et al., 2023), as well as support differentiated learning (Rassyi & Mauludin, 2024), critical thinking, and collaboration (Fauzan & Setiana, 2024). Furthermore, the application of VR in Project-Based Learning (PjBL) has been proven to improve problem-solving skills (Fitri et al., 2025) and strengthen concept retention (Purnama et al., 2025).

These benefits are consistent with classical and contemporary learning theories. Piaget's cognitive development theory highlights that elementary students in the concrete operational stage require concrete and visual experiences to understand abstract concepts, which VR provides through manipulable 3D models (Gambo & Shakir, 2022). Bruner's learning theory emphasizes progression from enactive to iconic and symbolic representations, a pathway effectively supported by VR-based simulations (Ali & Hassan, 2023). Ausubel's advance organizer theory stresses the role of prior knowledge in concept formation, which VR can strengthen by offering contextual cues and previews (Setiawan, 2023). Vygotsky's Zone of Proximal Development underscores scaffolding, where guided inquiry and interactive prompts in VR help learners extend their capabilities (Chen et al., 2023). Meanwhile, connectivism provides a modern lens by stressing knowledge distribution across networks, aligning with VR's potential to foster collaboration and digital literacy in the Education 5.0 era (Zulaikha et al., 2025).

MilleaLab is one of the VR platforms in education that enables teachers and students to design learning content without programming skills (Suhardi et al., 2025). Its advantages include an intuitive interface, compatibility with low-cost devices, and the availability of ready-to-use content aligned with the national curriculum (Hidayat et al., 2024). Several studies demonstrate the effectiveness of MilleaLab VR, for example, in improving students' cognitive abilities (Fauzan & Setiana, 2024), learning motivation (Assidiq et al., 2025), and integration with other digital learning models (Anjarwati et al., 2024). However, most of these studies still focus on individual aspects, such as motivation or critical thinking, rather than comprehensively addressing both conceptual understanding and digital literacy in elementary schools (Santosa et al., 2024).

Based on these conditions, there is a research gap regarding comprehensive studies on the effectiveness of MilleaLab VR in improving both scientific conceptual understanding and digital literacy among elementary school students within the framework of Education 5.0. Therefore, this study aims to investigate the role of MilleaLab VR in transforming science learning by enhancing students' conceptual understanding and digital literacy. The novelty of this research lies in implementing VR within the Education 5.0 framework, focusing on elementary school learners while considering the national curriculum context. This study is expected to provide theoretical contributions to technology-based learning literature and practical insights for teachers in designing interactive, contextual, and digitally literate learning experiences.

Method

This study employed a Research and Development (R&D) approach using the ADDIE model, which consists of five systematic stages: Analysis, Design, Development, Implementation, and Evaluation (Ranuharja et al., 2021). The model was selected for its

flexibility in integrating modern instructional technology at each stage of instructional design, as highlighted in recent literature (Spatioti et al., 2022; Lestari, 2024). The overall research procedure is illustrated in Figure 1.

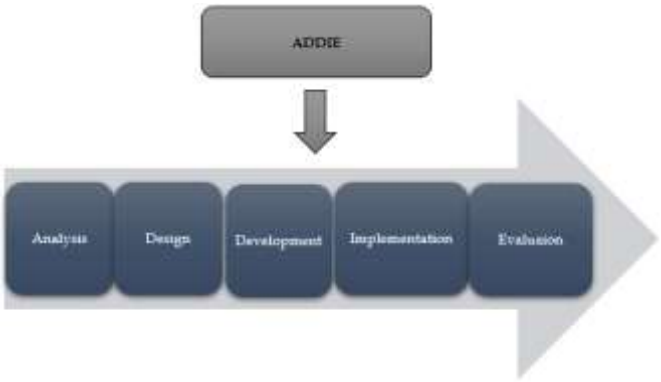

Figure 1. Research procedure ADDIE model

Analysis

In the analysis stage, the needs of teachers and students were identified through classroom observations, interviews, and teacher questionnaires. The analysis focused on: learning objectives in the science curriculum for Phases B and C, limitations of existing learning media, and science topics frequently perceived as difficult by students, such as the role of green plants (Grade IV) and the human digestive system (Grade V). The findings from this stage informed the selection of content, VR features, and digital literacy indicators for development.

Design

The design stage translated the analysis results into a product framework. At this stage, the VR content was developed as interactive 3D simulations incorporating stand points, portals, pop-up information elements, custom images, and integrated videos. The instructional content was adapted from the official SIBI textbooks corresponding to each grade level. Differences in grade level and school context were also considered, as these may influence the effectiveness of the learning product. To enhance visual appeal, learning materials were initially designed in Canva and then embedded as custom images within the VR platform. The final VR product was supplemented with visual flows and narration aligned with the learning objectives, and fully synchronized with the competencies outlined in the Indonesian Merdeka Curriculum, ensuring contextual conceptual understanding.

Development

The development stage involved producing the media using the MilleaLab platform. Validation was conducted by one content expert and one media expert using a 5-point Likert scale (1 = very poor to 5 = excellent). Validation scores were calculated by dividing the total obtained score by the maximum possible score, then converting the result into a percentage. The product was considered feasible if it achieved a minimum mean score of 80%, following common practice in recent studies employing the ADDIE model (Aris & Mansor, 2023; Shakeel, 2023). Products that did not reach this threshold were revised based on expert feedback before implementation.

The validated product was then further refined according to expert suggestions. For instance, instructional content on green plants was enhanced by adding more contextual illustrations, while online videos originally linked from YouTube were replaced with offline videos created by the researcher to ensure classroom stability. Adjustments to stand points were also made to improve visual precision across scenes.

Implementation

The implementation stage was carried out in four elementary schools in East Java, involving a total of 225 students from Grades IV and V. The sample distribution included 34 students from School A (Grade V), 58 students from School B (Grade IV), 79 students from School C (Grade IV), and 54 students from School D (Grade V). Grade IV students studied the green plants topic, while Grade V students studied the digestive system, based on the needs identified during the analysis stage.

The procedure began with a pre-test to measure students' prior knowledge, followed by concept presentation tailored to each grade, after which students engaged in guided inquiry activities using MilleaLab VR. A post-test was administered at the end of the session to assess learning gains. Student perceptions of the VR media were collected using a reflection sheet consisting of two components. The first was a 5-point Likert scale (1 = very poor to 5 = excellent) across six aspects: attractiveness, ease of use, clarity of content, relevance to the science subject, usefulness for conceptual understanding, and interest in future VR-based learning. The six-item reflection questionnaire employed a 5-point Likert scale (1 = very poor to 5 = excellent), yielding a maximum score of 30. Following the classical approach to Likert scoring (Likert, 1932; Nunnally & Bernstein, 1994) and consistent with recent methodological recommendations (Jebb et al., 2021), students' total scores were converted into categorical interpretations based on percentage intervals of the maximum score: very poor (≤ 20%), poor (21–40%), fair (41–60%), good (61–80%), and very good (81–100%). For a six-item, 5-point instrument, this corresponds to cut-

off ranges of ≤ 6, 7–12, 13–18, 19–24, and 25–30. This method of classification aligns with contemporary practices in scale validation and interpretation within virtual learning environments (Ustun et al., 2022). The second component comprised three open-ended reflection questions, asking students to describe what they liked most about the lesson, what they still found difficult, and their expectations for future learning.

Evaluation

The evaluation stage included both formative and summative evaluations. Formative evaluation was conducted during the development stage through expert validation and limited student trials, allowing weaknesses to be identified and revisions made. Summative evaluation was conducted after implementation, involving analysis of pre-test and post-test results along with student reflections. Learning improvement was measured using the normalized gain (N-Gain) formula:

$$\text{N} - \text{Gain} = \frac{\text{Post Test} - \text{Pre Test}}{100 - \text{Pre Test}} \quad (1)$$

Description:
Pre-test = students' initial score
Post-test = students' final score
Maximum score = ideal score (100)

The interpretation categories followed general standards: high (≥ 0.70), medium (0.30–0.69), and low (≤ 0.29) (Hake, 1998; PhysPort, 2020; Fadilah, 2021). Hake (1998) serves as a classical reference for N-Gain interpretation, which remains widely adopted in educational research, while PhysPort (2020) and Fadilah (2021) reinforce its contemporary relevance. It should be noted that this study did not employ a control group; therefore, the findings primarily reflect the effectiveness of VR media within the studied context rather than causal comparisons with alternative instructional methods.

Result and Discussion

Result

Validation Test Results

Media Expert Validation Test

The media expert validation was carried out by Dr. Singgih Bektiarso, M.Pd., M.C.E., a lecturer at the Faculty of Teacher Training and Education (FKIP), University of Jember. The assessment was conducted on August 12, 2025.

Table 1. Media expert validation results

Validator	SM	NP%
Dr. Singgih Bektiarso, M.Pd., M.C.E.	29	96.67
Average		96.67 (Feasible with minor revision)

Validation by the media expert on the VR-based learning media (MilleaLab) developed obtained a total score of 29 out of a maximum score of 30, resulting in a validity percentage of 96.67%. Referring to Aris & Mansor (2023) and Shakeel (2023), a product is declared feasible if it achieves a minimum average value of 80% in studies that apply the ADDIE model. Therefore, the developed product is categorized as feasible with minor revision and can be implemented in the subsequent stage.

Material Expert Validation Test

The material expert validation was conducted by Hasyim As'ari, S.Pd., M.Pd., a lecturer at the Faculty of Mathematics and Natural Sciences (FMIPA), Biology Education Study Program, PGRI University of Banyuwangi. The assessment was carried out on August 20, 2025.

Table 2. Results of material expert validation

Validator	SM	NP%
Hasyim As'ari, S.Pd., M.Pd.	29	96.67
Average		96.67 (Feasible without minor revision)

Validation by the material expert on the VR-based learning media (MilleaLab) developed obtained a total score of 29 out of a maximum score of 30, resulting in a validity percentage of 96.67%. Referring to Aris & Mansor (2023) and Shakeel (2023), a product is considered feasible if it achieves a minimum average value of 80% in studies employing the ADDIE model. Therefore, the developed product is categorized as feasible without minor revision and can be implemented in the subsequent stage.

Effectiveness Test Results

Pre-test and Post-test Results

The validated product was implemented in four elementary schools in East Java, involving a total of 225 students from Grades IV and V.

Table 3. Mean pre-test and post-test scores

School	Grade	Number of students	Pre-test	Post-test	N-gain
SD A	V	34	68.07	93.75	0.88
SD B	IV	58	61.86	85.30	0.60
SD C	IV	79	59.65	77.32	0.46
SD D	V	54	69.81	75.00	0.07
Mean		225	64.85	82.84	0.50

Note: Interpretation of N-Gain: high (≥ 0.70), moderate (0.30–0.69), low (≤ 0.29).

The overall analysis of the learning outcomes using N-Gain showed a mean score of 0.50, which falls into the moderate category (0.30–0.69) according to general standards (Hake, 1998; PhysPort, 2020; Fadilah, 2021). Among the four schools, SD A achieved a high N-Gain (0.88), SD B reached a moderate level (0.60), SD C was also in the moderate category (0.46), while SD D showed a low improvement (0.07). This indicates that the developed product was generally effective in improving students' learning outcomes, although the level of effectiveness varied across schools.

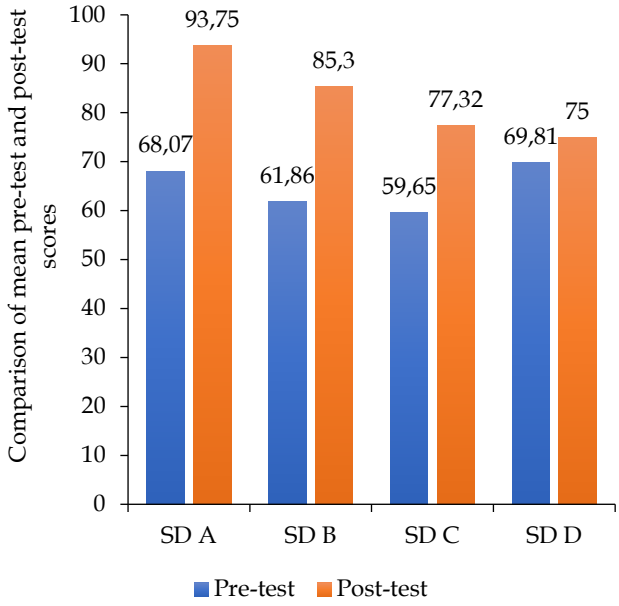

Figure 2. Comparison of mean pre-test and post-test scores

The Students' Responses Through the Questionnaire in the Form of Reflection Sheets

After assessing learning outcomes through the pre-test and post-test, students' perceptions were measured using reflection questionnaires. The six-item, 5-point Likert scale instrument was completed by 225 students.

Table 4. Students' reflection questionnaire results

Interval	Interpretation category	f	%
25–30	Very good	137	60.89
19–24	Good	74	32.89
13–18	Fair	14	6.22
7–12	Poor	0	0
0–6	Very poor	0	0

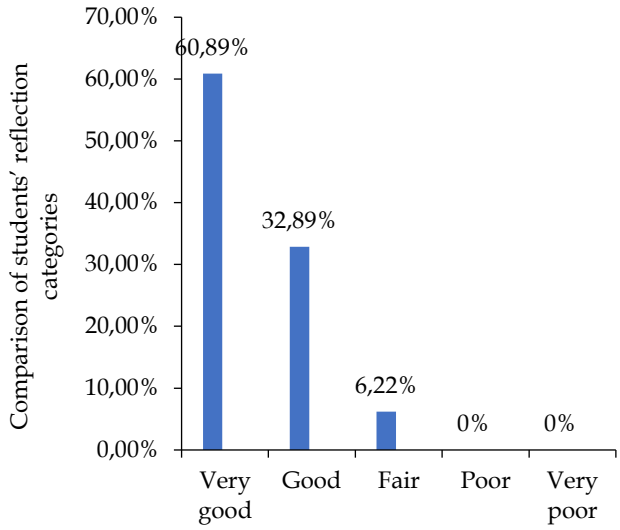

Figure 3. Comparison of students' reflection categories

The results of the reflection questionnaire indicate that the majority of students (60.89%) rated their learning experience as very good, while 32.89% assessed it as good. Only a small proportion (6.22%) fell into the fair category, and none reported poor or very poor experiences. Based on the classification approach to Likert scoring (Likert, 1932; Nunnally & Bernstein, 1994) and supported by recent methodological insights (Jebb et al., 2021), these findings suggest that students' overall perceptions were highly positive. Furthermore, this outcome aligns with contemporary practices in evaluating learning media within virtual environments (Ustun et al., 2022), reinforcing that the developed product effectively fostered engaging and meaningful learning experiences.

Discussion

From a theoretical perspective, Piaget's cognitive development theory positions students in Grades IV and V within the concrete operational stage, where learners benefit most from visual and manipulable representations to construct meaning from abstract phenomena. This developmental readiness aligns with the affordances of VR, which provides immersive and interactive 3D visualizations that enhance conceptual clarity (Gambo & Shakir, 2022). Similarly, Bruner's learning theory emphasizes the progression from enactive to iconic and symbolic representations, and the integration of 3D simulations, narration, and visual cues in MilleaLab VR reflects this pathway by guiding students from concrete interactions toward more abstract scientific reasoning (Ali & Hassan, 2023).

Ausubel's advance organizer theory further explains why VR can effectively support conceptual understanding: by linking new information to students' prior knowledge, immersive media helps strengthen

schema formation. Studies have shown that providing pre-training or concept maps in VR significantly reduces misconceptions and enhances retention (Setiawan, 2023). At the same time, Vygotsky's Zone of Proximal Development (ZPD) underscores the role of scaffolding in extending students' capabilities beyond their current level. In this study, guided inquiry and structured prompts within MilleaLab VR supported learning in ways consistent with research demonstrating that scaffolding reduces cognitive load and deepens understanding (Chen et al., 2023).

Nonetheless, the small proportion of students categorized as Fair (6.22%) suggests that benefits of VR were not equally distributed. Variability may be linked to differences in students' digital literacy, prior exposure to technology, or cognitive readiness. Huang (2024) similarly reported that learners with lower digital confidence experienced weaker outcomes in VR-based learning. This highlights the importance of teacher facilitation, differentiated instruction, and gradual integration to ensure inclusivity.

Furthermore, challenges in infrastructure cannot be ignored. Unequal access to devices and unstable internet connectivity remains pressing issues in Indonesian schools. These findings resonate with broader analyses of the digital divide, which emphasize that such inequities directly mediate the effectiveness of digital innovations (Ramadhanti & Astuti, 2023; Zulaikha et al., 2025). Without systemic support for device provision and network stability, scaling VR integration across schools may exacerbate existing disparities.

Finally, connectivism provides a lens to interpret the role of VR in the Education 5.0 era, emphasizing that knowledge is distributed across networks and that learning depends on students' ability to form connections with peers, media, and resources. Recent studies confirm that VR can promote such connected learning environments, thereby fostering collaboration and digital literacy alongside conceptual mastery (Samala, 2023; Febriana & Cooper, 2024).

Overall, the results confirm that MilleaLab VR is both feasible and effective in supporting elementary science learning. However, effectiveness is conditional: it requires alignment with learners' developmental stages, incorporation of scaffolding and advance organizers, and provision of equitable access to digital infrastructure. Addressing these conditions in future practice will ensure the sustainable impact of VR as an innovation in science education.

Conclusion

This study found that the MilleaLab VR learning media, developed using the ADDIE model, exceeded the predefined feasibility threshold (≥ 80%) in expert validation and achieved a mean N-Gain of 0.59 (moderate), indicating improved students' conceptual understanding. These findings suggest that MilleaLab VR can support elementary science learning in the Education 5.0 era, provided sufficient device availability and teacher readiness.

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Author Contributions
Conceptualization, methodology, resources, project administration, funding acquisition, A.A.; validation, A.A., R.S.Q., and P.D.R.W.; formal analysis, writing—original draft preparation, A.A. and R.S.Q.; investigation, A.A., R.S.Q., D.A.P., S.N.L., and P.D.R.W.; writing—review and editing, R.S.Q., S.N.L., and P.D.R.W.; visualization, D.Y.P. and P.D.R.W. All authors have read and approved the published version of the manuscript.

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Conflict of Interest
The authors declare no conflict of interest.

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