

Available online at

PISCES

Proceeding of Integrative Science Education Seminar

Beranda prosiding : <https://prosiding.iainponorogo.ac.id/index.php/pisces>

Article

HydroVolt City: Smart Ecology Learning Media that Bridges Physics, Biology, and Sustainability in One Smart Energy System

Martha Loviana^{1*}, Dwi Ana Rahmawati², Desi Ayu Nur Saputri³, Wida Nailil Asna⁴

¹²³⁴ Universitas Islam Negeri Kiai Ageng Muhammad Besari Ponorogo, Ponorogo

*Corresponding Address: marthatatha500@gmail.com

Corresponding Address: marthaanddwi500@gmail.com	
Article Info	ABSTRACT The development of science and technology in the Society 5.0 era demands contextual education oriented towards 21st-century competencies. Science education that is still taught separately often makes it difficult for students to understand the interrelationships between physics, biology, and the environment. In response to this challenge, the 3D <i>HydroVolt City</i> learning media was developed as a Smart Ecology Learning Media that bridges Physics, Biology, and Sustainability in a Single Smart Energy System. This media integrates the principles of hydraulic pressure, energy conversion, and ecosystem balance in the form of a mini city based on renewable energy. This study used the Research and Development (R&D) method with a 3D model according to Thiagarajan, which includes define, design, and develop. Define includes analyzing student needs, design includes compiling and developing integrated physics and biology learning media, and development includes validation testing by experts. The research subjects consisted of three validators, namely science teachers in Ponorogo Regency. The instrument used was a validation sheet with a five-point Likert scale that assessed the aspects of material suitability, accuracy, durability, efficiency, aesthetics, and safety of the tools. The validation results showed an average validity score of 84% (very valid category), with details of validator I 83%, validator II 84%, and validator III 85%. Thus, the <i>HydroVolt City</i> media is declared suitable for use in learning.
5 st AVES Annual Virtual Conference of Education and Science 2025	
Keywords: <i>Expert Validation; Integrated Science; Learning Media; Renewable Energy; R&D.</i>	
	© 2025 Martha Loviana, Dwi Ana Rahmawati, Desi Ayu Nur Saputri, Wida Nailil Asna.

INTRODUCTION

In the era of Society 5.0, technological developments require the world of education to provide interactive, innovative, and contextual learning. Natural Sciences (IPA), as one of the core disciplines in science education, has a strategic role in equipping students to think critically, creatively, and care about environmental sustainability. Today's education should not only emphasize the mastery of theoretical concepts but also foster 21st-century skills such as systemic thinking, collaboration, and responsiveness to global environmental issues (Khut & Shimizu, 2021). Thus, science education needs to be developed to connect science, technology, and environmental values in the context of real life.

However, in practice, science education at the junior high school level is still partial, where the concepts of physics, biology, and chemistry are taught separately. As a result, students often find it difficult to relate the concepts they learn to their daily activities, thereby reducing the

contextual meaning of science. This separation between subjects also prevents students from seeing the connections between natural phenomena as a whole. Therefore, learning media is needed that can serve as a conceptual bridge to connect various science concepts into an integrated system (Octaviani & Dwanda, 2021).

The use of interactive, innovative, and engaging learning media has been proven to increase student motivation and understanding through concrete learning experiences. Miniature-based or 3D model learning media can provide clear and easy-to-understand visual representations for students, thereby strengthening the connection between theory and practice (Octaviani & Dwanda, 2021). This is reinforced by Khoirunnesa et al. (2023), who state that integrating learning that combines visual aspects, real experiments, and contextual problems can increase the effectiveness of science learning while fostering students' scientific curiosity.

Research shows that integrating local wisdom into science learning has been proven to improve students' conceptual understanding, process skills, and interest in learning because context-based learning helps them relate scientific knowledge to their daily lives (Sudirman, 2025). In addition, the results of research conducted by Savitri and Susanti (2024) show that the application of project-based learning in ecosystem material can increase students' creativity and scientific process skills because this method provides space for them to actively participate in the planning, implementation, and evaluation of scientific projects.

However, research that specifically combines project-based learning models that integrate physics and biology concepts into a single sustainable energy system is still limited. In fact, this kind of integrative model has great potential to improve students' scientific thinking skills, creativity, and ecological awareness in the context of sustainability-oriented science learning (Sihombing et al., 2025).

As a solution to these problems, the *HydroVolt City* 3D learning media was developed, which is a smart ecological medium capable of bridging the concepts of physics, biology, and environmental sustainability in one smart energy system. This medium integrates the principles of Pascal's Law, energy conversion, and ecosystem balance in the form of a miniature city based on renewable energy. This innovation is in line with the direction of the Merdeka Curriculum policy, which emphasizes 3M learning, namely Mindful, Meaningful, and Joyful. With contextual and collaborative reinforcement to develop the Pancasila Student Profile. Through the use of the *HydroVolt City* media, students are expected to strengthen their scientific literacy, increase their ecological awareness, foster social responsibility, and build a spirit of sustainable innovation in facing future challenges

HydroVolt City focuses on several key issues. The first issue concerns how to design project-based learning media that can integrate physics concepts, particularly Pascal's Law and electrical circuits, with biological concepts about ecosystems so that the two are connected in a single, comprehensive, and applicable system. The second issue focuses on the effectiveness of *HydroVolt City* media in improving students' understanding of the concepts of energy, pressure, and their relationship to ecosystem sustainability through contextual learning experiences. Furthermore, how can the principles of environmental sustainability be optimally implemented through interactive project-based learning media, so that science learning not only fosters scientific thinking skills but also ecological awareness and responsibility for environmental conservation.

The purpose of this article is to explain in depth the process and principles behind the development of the *HydroVolt City* learning media, which integrates biology and physics concepts into a single integrated system. Through this research, it is hoped that the effectiveness of *HydroVolt City* as a learning tool can be analyzed in terms of improving students' conceptual understanding and developing their critical thinking skills in the context of science learning. In addition, this article aims to explain the role of this learning media in fostering students' ecological awareness and systemic thinking skills, so that they can

understand the relationship between technology, energy, and environmental sustainability in accordance with 21st-century competency requirements.

In theory, this paper contributes to the development of integrated science learning theory, particularly the integration of biology and physics learning. This approach is expected to strengthen the relationship between science and sustainable environmental values in science education. From a practical perspective, the results of this study also provide benefits for various parties. For teachers, the *HydroVolt City* media can be an innovative example in improving the quality of science learning that is relevant to everyday contexts and more interactive. For students, this media provides a meaningful learning experience through experiments and real projects that involve observation, analysis, and direct problem solving. In addition, for researchers, this work can be used as a basis for further research in the field of developing technology-based learning media for the environment and renewable energy, which is in line with the direction of sustainable education today.

METHOD

Research Approach

This study uses a research and development (R&D) approach with a 3D model (Define, Design, and Development) adapted from Thiagarajan, Semmel, and Semmel (1974). This model was chosen because it is suitable for developing and assessing the feasibility of learning media before it is implemented in teaching and learning activities. According to Indaryanti et al. (2025), the 3D R&D model is a form of educational product development that emphasizes expert validation as the main indicator in determining the quality and feasibility of learning media.

Research Design

This research was conducted in three main stages, namely Define, Design, Development, and Validation.

1. Define

The definition stage aims to determine the basis for media development based on the results of needs analysis and literature review of science learning. At this stage, a theoretical review of the integration of physics, biology, and environmental concepts was conducted, as well as an examination of the principles of hydraulic pressure, energy conversion, and ecosystem balance, which form the basis for the design of the *HydroVolt City* media. According to Adawiyah et al. (2022), the definition stage is important to determine the scope of the material and product specifications so that they are relevant to the learning context.

2. Design

The design stage was carried out by creating a preliminary design for the *HydroVolt City* learning media in the form of a miniature smart city based on renewable energy that integrates the concepts of Pascal's Law, electrical-mechanical energy conversion, and sustainable ecosystem balance. This design includes the creation of flowcharts, electrical circuit diagrams, and hydraulic system working diagrams. Aspects considered in the design include energy efficiency, user safety, and the visual aesthetics of the media. In addition, at this stage, expert validation instruments were also developed, consisting of assessment sheets for media experts and subject matter experts. According to Hariyanto et al. (2022), the design stage is an important process in development.

3. Development

Tahap The development stage is the main process that focuses on product creation and validation. *HydroVolt City* media was developed using simple materials,

such as solar panels, hydraulic injections, DC motors, cables, and LED lights, which were assembled into a two-level miniature energy system. After the prototype was completed, it was validated by media and material experts to assess product quality based on specific criteria.

- 1) Media expert validation assesses six aspects: effectiveness, ease of use, suitability, completeness, communicative interaction, and tool safety for students.
- 2) Material expert validation assesses four aspects: content suitability, material completeness, ease of understanding, and concept clarity.

Average Rating per Validator

$$P = \frac{\text{scores obtained}}{\text{max skor}} \times 100\%$$

Final Value of Validation Test

$$\text{Final Value of Validation Test} = \frac{\sum \text{validator final value}}{\sum \text{validator final value item}}$$

Table 1. eligibility criteria for media instruments are as follows

Score Interval	Information
4, 21 – X – 5, 00	Very good
3, 41 – X – 4, 20	Good
2, 61 – X – 3, 41	Enough
1, 81 – X – 2, 60	Not Enough
1, 00 – X – 1, 80	Very Less

The assessment was conducted using a five-point Likert scale, ranging from 1 (very poor) to 5 (very good). The media was categorized as valid if it obtained a validity score of $\geq 80\%$. According to Ramadhani (2023), expert validation is an important stage in development research because it forms the basis for determining the feasibility of a product before it is tested in the field.

Research Procedure

This research procedure was carried out through several stages that were systematically arranged so that the development process of the *HydroVolt City* learning media was focused and measurable. The first stage was to determine the focus of media development by conducting an in-depth study of integrated science learning theory and analyzing science learning needs in schools. This step aimed to ensure that the media developed was relevant to the curriculum requirements and characteristics of the students.

The second stage is to design a miniature *HydroVolt City* scheme that integrates Pascal's Law principles, electrical energy concepts, and sustainable ecosystems. This design is intended to illustrate the relationship between technological systems and ecological processes in a model that is applicable and easy for students to understand. Next, in the third stage, the researchers developed validation instruments, including assessment sheets for media experts and subject matter experts. The instruments used a five-point Likert scale to assess the feasibility of the content, appearance, conceptual integration, and usefulness of the media in learning.

The fourth stage is validation by experts, in which each expert provides an assessment and input on the technical and substantive aspects of the *HydroVolt City* media. After all the validation data has been collected, the fifth stage is carried out by calculating the average score of the assessment results to determine the level of product validity. This analysis provides an overview of the extent to which the media meets the criteria for theoretical and practical

feasibility. The final stage is to draw conclusions based on the experts' assessment results to determine the feasibility level of the *HydroVolt City* learning media before it is used in field trials or classroom implementation.

Data Collection Techniques

Data was collected through validation instruments given to media experts and subject matter experts. The instruments took the form of closed questionnaires with measurable indicators covering aspects of effectiveness, suitability, completeness, ease of use, security, and clarity of concept. The data obtained was analyzed using quantitative descriptive analysis to calculate the percentage of learning media feasibility.

This research was conducted as a desk study in October 2025. The validation process was conducted online by sending digital validation instruments to three validators, consisting of junior high school/MTS science teachers in Ponorogo Regency. Each validator provided assessments and development suggestions through an online validation form and documentation files, which were then analyzed to determine the feasibility level of the *HydroVolt City* media.

RESULT AND DISCUSSION

This research was conducted using a 3D development model (define, design, and develop), resulting in an innovative learning media product in the form of 3D *HydroVolt City* as a representation of cross-curricular science learning materials in the fields of physics and biology, as well as a support for the learning activities of junior high school/MTs students in Ponorogo Regency.

Define Stage

The Define stage is the first step in the process of developing *HydroVolt City* learning media with a 3D model (Define, Design, Develop). This stage aims to determine the direction and needs of media development through learning needs analysis, curriculum analysis, and scientific literature review. All processes are carried out through desk studies, without direct data collection in the field.

At this stage, the researchers first identified the main problems in science learning at the junior high school/MTs level. Based on the results of various studies, it is known that science learning is still delivered separately between the fields of physics and biology. As a result, students often find it difficult to understand the relationship between scientific concepts and their application in real life (Octaviani & Dwanda, 2021). This condition shows the need for learning media that can connect various science concepts in an integrated manner in an attractive and easy-to-understand system.

Next, a curriculum analysis was carried out to adjust the media to the learning outcomes in the Merdeka Curriculum. Based on the results of the study, it was determined that the *HydroVolt City* media would integrate the material on Pascal's Law (fluid pressure), electrical-mechanical energy conversion, and ecosystem balance, because the three have a logical relationship that can be visualized concretely. According to Adawiyah et al. (2022), the definition stage is very important to ensure that the scope of the material is

In addition, researchers conducted a scientific literature review to strengthen the theoretical basis for development. The review showed that project-based 3D media is effective in improving students' conceptual understanding, learning motivation, and critical thinking skills (Khoirunnesa et al., 2023; Iswanto et al., 2024). Based on the results of this study, *HydroVolt City* was designed as a miniature city based on renewable energy that combines the principles of hydraulic pressure, energy conversion, and ecosystem balance.

The results of the Define stage produced the initial product specifications, namely interactive, environmentally friendly, three-dimensional (3D) learning media that is suitable for junior high school/MTs students. This stage also ensured that the media developed was not only visually appealing but also relevant to the context of modern science learning, which emphasizes the integration of science, technology, and environmental sustainability. This is in line with the opinion of Nurhidayati and Wardani (2024), that the success of a development product greatly depends on the accuracy of the needs analysis and the determination of the direction of development in the definition stage.

Thus, the Define stage is an important basis for the development of *HydroVolt City*, because it is from this stage that the concept, content, and objectives of the media are determined to suit the needs of science learning in secondary schools.

Design Stage

The next stage focuses on the process of designing learning media as the core of *HydroVolt City* product development. The design stage is an important process in the development of *HydroVolt City* learning media, which is intended for junior high school/MTs students to learn science concepts in a contextual and applicable manner. This media combines the concepts of physics, biology, and the environment into a smart city system based on renewable energy.

The design phase focuses on two main aspects, namely media selection and learning material design, taking into account the cognitive characteristics of junior high school/MTs students and the learning outcomes of the Merdeka Curriculum.

1. Media Selection

Media selection was carried out by considering the needs of junior high school/MTs students who tend to require concrete visualization and direct experience in understanding science concepts. Therefore, the media developed was a three-dimensional (3D) miniature in the form of a smart city that illustrates the integration of renewable energy and ecosystem balance. According to (Iswanto et al., 2024), the development of project-based integrated learning media has been proven effective in increasing junior high school/MTs students' learning motivation and understanding of science concepts because it connects scientific phenomena with everyday contexts.

The *HydroVolt City* media was developed using simple and environmentally friendly materials such as mini solar panels, DC motors, hydraulic injectors, LED lights, 3.7-volt lithium batteries, and recycled materials (cardboard and foam). These materials were selected based on the principles of safety, ease of use, energy efficiency, and durability, so that they can be used repeatedly in learning activities at junior high schools/MTs. The miniature design was created in two levels. The first level displays a natural ecosystem (water, plants, and fish) as a symbol of environmental balance. The second level depicts the application of energy technologies such as solar panels, electric-powered houses, and LED street lights. The two-level design aims to visually show the interconnection between science, technology, and the environment so that students can understand abstract concepts in a concrete and applicable way.

2. Material Design

The material design in *HydroVolt City* is based on junior high school/MTs science competencies, which cover four main topics, namely Pascal's Law (fluid pressure), simple electrical circuits, energy conversion, and ecosystems. All of these concepts are integrated through a scientific inquiry and project-based learning approach so that students can actively construct their knowledge.

1) Pascal's Law (Fluid Pressure)

Visualized through a hydraulic injection system that powers solar panels. This process demonstrates the principle of pressure in a closed fluid being transmitted evenly in all directions

2) Simple Electrical Circuits

Displayed through an electrical system that uses solar panels, DC motors, cables, and lithium batteries to explain the flow of current and the storage of electrical energy.

3) Energy Conversion

Illustrates the conversion of light energy into electrical energy, kinetic energy, and light energy, in accordance with the principles of physics taught in junior high school/MTs.

4) Ecosystem

Visualized through elements of plants, water, and artificial fish as a representation of the balance between technological systems and the environment



The HydroVolt City learning media is designed in the form of a two-level three-dimensional (3D) model that integrates the concepts of physics, biology, and the environment into one integrated system. On the first level, there are water wheels, ponds, fish, and plants that serve as representations of a simple ecosystem. This section shows the relationship between living things and their surrounding abiotic environment. This section also contains two 3.7-volt lithium batteries that serve as the main power storage center. Another important component at this level is a hydraulic pump used to implement Pascal's Law, whereby pressure applied to a fluid in a closed system is transmitted evenly throughout the fluid.

Meanwhile, the second level features a miniature town consisting of houses, trees, street lights, and windmills. These components represent the application of renewable energy in sustainable urban living.

Constructively, this medium is made with a plywood base covered with foam rubber to make it more sturdy, lightweight, and visually appealing. The supporting structure uses lightweight wood so that the medium is stable, durable, and easy to move. This physical design not only highlights aesthetic aspects but also considers safety and ease of use in the learning environment.

The mechanism of the media is designed to show the sequential and tangible process of energy conversion. When the solar panel receives sunlight, the solar cells convert the light energy into approximately 24 volts of electrical energy. This energy is then channeled to two 3.7-volt lithium batteries through a type C charging module for temporary storage. The electrical energy stored in the batteries is then transferred to a DC motor, which drives two main components, namely water wheels and wind turbines.

The rotating motion of both wheels is a direct visualization of the process of converting electrical energy into mechanical energy, while also generating additional power used to light two 5-volt LED lights. The lit LED lights illustrate the end result of an efficient and sustainable energy flow system.

Overall, the HydroVolt City system demonstrates the flow of energy from the source of sunlight to its utilization as electrical energy for lighting a miniature city. This illustrates the application of the principle of integrated science learning in the context of environmentally friendly technology.

The HydroVolt City design not only highlights technical aspects but also considers pedagogical values and the context of 21st-century learning. Through this medium, students can directly observe the application of the concepts of fluid pressure, energy conversion, and ecosystem balance in a single integrated model. Thus, the learning process becomes more interesting, meaningful, and supports the strengthening of students' science and technology literacy and ecological awareness.

According to Lestari et al. (2025), the SETS (Science, Environment, Technology, and Society) approach in junior high school science education can improve students' critical thinking skills and environmental awareness through the integration of scientific concepts with the application of technology and ecological issues. Additionally, Mukti (2022) emphasizes that ethnoscience-based science education at the junior high school level can strengthen students' social responsibility and independence in understanding the relationship between science and the environment.

Thus, *HydroVolt City* not only presents scientific concepts visually but also builds critical thinking skills, science literacy, and ecological awareness in line with the values of the Pancasila Student Profile.

Based on the results of the design, the *HydroVolt City* media is considered effective as a medium for science learning at the junior high school/MTs level that supports conceptual understanding and scientific attitudes. Through a two-level miniature connecting energy and ecosystem aspects, students can directly understand the interconnection between technology and nature. Additionally, this medium aligns with the implementation of the Merdeka Curriculum, which emphasizes project-based learning, character-oriented education, and environmental awareness.

Development Stage

Next is the development stage, which is the final step in the Research and Development (R&D) method using the 3D model (Define, Design, and Develop). At this stage, development is carried out based on the design stages, taking into account the feasibility of the *HydroVolt City* media before it is used in teaching and learning activities. The feasibility of the media and materials was tested by experts, namely junior high school/MTs science teachers in Ponorogo Regency.

There were three validators in the *HydroVolt City* media validation process, which was carried out by filling out a questionnaire. The questionnaire contained assessments of the suitability of the material, the durability of the tools, the accuracy of the tools, the efficiency of the tools, the aesthetics, and the safety of the tools. After all the validation questionnaire instruments were filled out by the validators, the next step was data processing. The data obtained from the expert validation sheet evaluation was then processed into quantitative data based on the assessments of media experts and material experts, which was then analyzed in the form of percentages. Furthermore, the evaluation and validation results from the experts also include comments or suggestions and recommendations regarding product revisions, which will later be described by the researcher descriptively to be used as a basis for improving the media or product. The validation test results are presented in the following diagram.

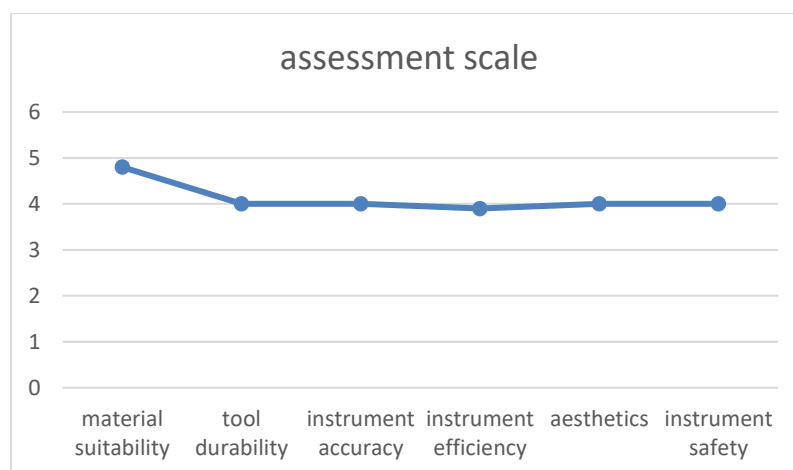


Figure 1. Results of Validation Test I

The results of media expert validation from one of the science teachers at Ponorogo State Junior High School show six assessment indicators, namely Material Suitability, Tool Durability, Tool Accuracy, Tool Efficiency, Aesthetics, and Tool Safety. Each indicator received a high score, with an average score of 4.5, which is classified as very good. Several inputs from media experts stated that the *HydroVolt City* 3D media meets the criteria for media that is capable of supporting the learning process in terms of both material and media with a percentage score of

$$P = \frac{4,5}{5} \times 100\% = 90\%$$

Overall, *HydroVolt City* is considered excellent and suitable for use in science education that bridges physics and biology.

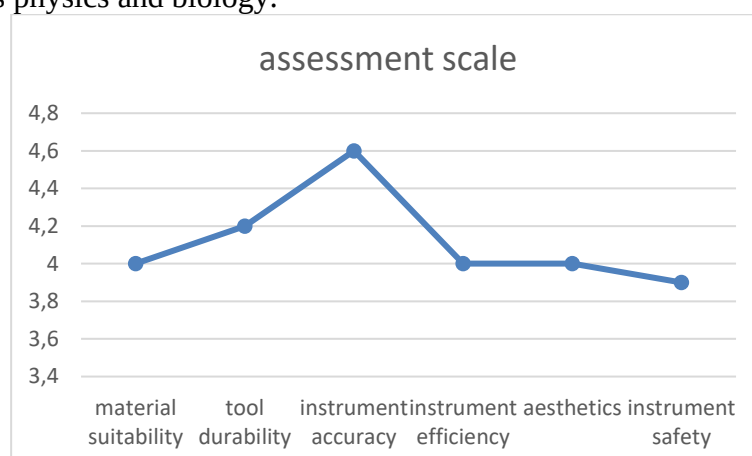


Figure 2. Results of Validation Test II

The results of media expert validation from one of the science teachers at Ponorogo State Junior High School show six assessment indicators, namely Material Suitability, Tool Durability, Tool Accuracy, Tool Efficiency, Aesthetics, and Tool Safety. Each indicator received a high score, with an average score of 4.8, which is classified as very good. Some feedback from media experts stated that the cables in the *HydroVolt City* 3D media should be neatly arranged and detailed explanations related to the guidebook should be provided so that students can learn independently. There should also be additional quizzes to test the students'

level of understanding. Based on this second validation test, the *HydroVolt City* learning media obtained the following percentage scores:

$$P = \frac{4,8}{5} \times 100\% = 96\%$$

Overall, *HydroVolt City* is considered excellent and suitable for use in science education that bridges physics and biology, with revisions as suggested.

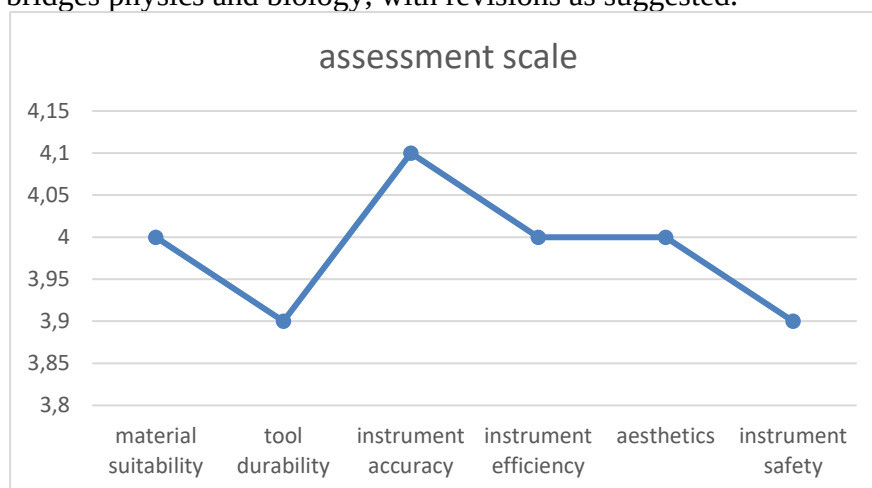


Figure 3. Results of Validation Test III

The results of media expert validation from one of the science teachers at MTs Negeri Ponorogo showed six assessment indicators, namely Material Suitability, Tool Durability, Tool Accuracy, Tool Efficiency, Aesthetics, and Tool Safety. Each indicator received a high score, with an average score of 4.1, which is classified as very good. Some feedback from media experts stated that the *HydroVolt City* 3D media requires a lot of time for its development process, so in terms of time, it is still not efficient. Therefore, based on this third validation test, the *HydroVolt City* learning media obtained the following percentage scores:

$$P = \frac{4,1}{5} \times 100\% = 82\%$$

Overall, *HydroVolt City* is considered excellent and suitable for use in science education that bridges physics and biology. It explains concepts well and simplifies the delivery of learning materials in the classroom.

Based on the results of the checks conducted by three validators, the overall average score was $4.5+4.8+4.1= 13.4$ with 3 validators, resulting in a Final Value of Validation Test using the formula:

$$\text{Final Value of Validation Test} = \frac{4,5 + 4,8 + 4,1}{3} = \frac{13,4}{3} = 4,46$$

This figure indicates that the learning media created falls into the “very good” category based on the assessment criteria used in Table 1. The eligibility criteria for media instruments are as follows.

These results indicate that, in general, *HydroVolt City* media is suitable for use in the teaching and learning process because it meets several important aspects of assessment, such as effectiveness, ease of use, suitability of content, completeness of components, interactivity, and safety for students.

With an average validation score of 4.46 (excellent category), it can be concluded that the *HydroVolt City* 3D learning media has met all the feasibility aspects set out in this study. These results show that this media is suitable for use in science learning activities because it meets the criteria of effectiveness, ease of use, material suitability, component completeness, interactivity, aesthetics, and safety for students.

In terms of content, *HydroVolt City* has proven to be able to bridge the interdisciplinary concepts between Physics and Biology, particularly in the material on fluid pressure (Pascal's Law), electrical-mechanical energy conversion, and ecosystem balance. This integration provides a holistic learning experience, where students can see the relationship between scientific principles and technological applications in the context of environmental sustainability. This aligns with the direction of science education in the Merdeka Curriculum, which emphasizes the integration of science, technology, and environmental values.

From a media design perspective, *HydroVolt City* presents an attractive visual representation through a two-level miniature that illustrates the relationship between technology and the natural ecosystem. This display is considered to make it easier for students to understand abstract concepts in a concrete and applicable way, while also fostering an interest in learning and scientific curiosity. The aesthetic and environmentally friendly design also reinforces the educational value of this media by instilling awareness of the importance of energy efficiency and renewable resource management.

From a learning perspective, this media provides a project-based learning experience that encourages students to think critically, collaborate, and develop problem-solving skills through direct exploration and experimentation. By manipulating media components such as solar panels, hydraulic systems, and ecosystem elements, students can understand the cause-and-effect relationships between scientific phenomena in a tangible way.

In addition, interactivity and safety are also important advantages. The media is designed using simple but safe materials such as cardboard, foam, hydraulic injections, and mini solar panels, which allow for repeated use in the classroom without risk to students. High interactivity allows students to learn independently, while teachers act as facilitators who guide the scientific investigation process.

Overall, the results of this study indicate that *HydroVolt City* is not only theoretically valid but also practical and effective as an integrative learning medium. Its use can improve students' science literacy, ecological awareness, and systemic thinking skills. Thus, this medium has the potential to be an alternative solution in facing the challenges of science learning that is still partial and lacks context at the junior high school/MTs level.

CONCLUSION

This research resulted in the innovative learning medium *HydroVolt City*, a smart ecological medium in the form of a two-level miniature city that integrates the concepts of Physics (Pascal's Law and energy conversion) and Biology (sustainable ecosystems) into a single renewable energy system. The development was carried out using a 3D R&D model (Define, Design, Develop) that focused on needs analysis, media design, and expert validation.

The results of validation tests by three validators showed an average validity rate of 84-90%, which falls into the "highly valid" category, so *HydroVolt City* is declared suitable for use in science learning at the junior high school/MTs level. This media has been proven effective in bridging the interconnection of cross-disciplinary science concepts, increasing learning motivation, and fostering ecological awareness and systemic thinking among students in accordance with 21st-century competencies. Thus, *HydroVolt City* can be an example of contextual and interdisciplinary learning media that supports the implementation of the Merdeka Curriculum and the strengthening of the Pancasila Student Profile. As a follow-up, it is recommended that future research conduct field trials to empirically assess the effectiveness

of this medium on student learning outcomes and develop a digital or interactive version to expand its accessibility and usefulness in technology-based science learning and environmental sustainability.

ACKNOWLEDGMENTS

The author would like to express his deepest appreciation and gratitude to Kiai Ageng Muhammad Besari State Islamic University Ponorogo for providing a forum for scientific development and for providing meaningful academic support and guidance during the research and writing of this article.

Ucapan The author would also like to thank the expert validators, namely science teachers at junior high schools/MTs in Ponorogo Regency, who participated in the validation process and provided constructive input for the improvement of the *HydroVolt City* learning media. Their views and suggestions have contributed significantly to improving the quality of the media and the accuracy of the learning content. The author would like to express sincere gratitude to the *HydroVolt City* media development research team for their cooperation, perseverance, and high level of collaborative spirit during the design, testing, and writing of this article. The synergy within this team was a major factor in the successful completion of this research with optimal results.

Finally, the author would like to thank all parties who have provided support, inspiration, and moral encouragement in completing this research. Hopefully, the results of this work can contribute to the development of integrative, innovative, and environmentally sustainable science education.

REFERENCE

- Adawiyah, R., Sari, D. N., & Prasetyo, E. (2022). Development of Integrated Science Learning Media Using the 4D Model to Improve Junior High School Students' Learning Outcomes. *Indonesian Journal of Science Education*, 10(3), 241–251.
- Iswanto, D., Rahmawati, N., & Anisa, R. (2024). The Effectiveness of Integrated Project Learning Media on Improving Science Concept Understanding in Junior High School. *Journal of Science Learning Innovation*, 8(1), 65–73.
- Khoirunisa, L., Kusuma, E., & Wulandari, S. (2023). Development of Miniature Learning Media for IPAS Water Cycle Material for Grade V Elementary School. *Didaktik: PGSD Scientific Journal*, 10(3).
- Khut, S., & Shimizu, K. (2021). Integrating STEM Approach in K-12 Science Education Teaching Practice: A Systematic Literature Review. *IJRSE*, 5(2).
- Lestari, I., Wahyurahmadina, S., Dwiningsih, S., Ismi, R., & Vennita, M. R. Y. (2023). The Impact of the SETS (Science, Environment, Technology, and Society) Approach in Science Education in Indonesia: A Systematic Review. *INKURI: Journal of Science Education*, 14(1), 66–75.
- Mukti, H., Suastra, I. W., & Aryana, I. B. P. (2022). Integration of Ethnoscience in Science Education. *Indonesian Journal of Science Education (JP-II)*, 7(2), 356–362.
- Nurhidayati, D., & Wardani, K. (2024). Analysis of Product Requirements and Specifications in the Define Stage of the 4D Model in the Development of Integrated Science Project-Based Media. *Journal of Science Education Innovation*, 8(2), 105–114.
- Octaviani, S. & Dwanda, L. 2021. The effectiveness of using miniature media to increase student motivation and learning outcomes in MUBATA elementary school science material. *Jurnal Fundadikdas (Fundamental Pendidikan Dasar)*. 4(2). 172-186.
- Pertiwi, T. U., Oetomo, D., & Sugiharto, B. (2023). The Effectiveness of STEM Project-Based Learning in Improving Students' Environmental Literacy Abilities. *JPBI*, 10(2).

- Putra, B. P., & Wahyuni, S. (2025). Integration of local wisdom in science learning to improve students' science literacy: A literature review. *Kalam Cendekia: Scientific Journal of Education*. <https://jurnal.uns.ac.id/jkc/article/view/103518>
- Riwanto, M. A., & Budiarti, W. N. (2024). Development of interactive science learning media for elementary school integrated with character education that cares for the environment. *Jurnal Pendidikan Dasar Nusantara*, 6(2) <https://doi.org/10.29407/jpdn.v6i2.14974>
- Syakbany, A. R., Mirza, Y., & Jumeilah, F. S. (2025). Development of interactive science learning media on force and energy for 4th grade elementary school students. *JTIMD: Journal of Digital Multimedia Information Technology*, 2(1), 63-72. <https://jurnal.polsri.ac.id/index.php/jtimd/article/view/10383>