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Article

Bio-Hydro Pressure Simulator: An Integrative Physics–Biology Tool for Visualizing the Concept of Fluid Pressure and the Circulatory System

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ABSTRACT

Natural Science (IPA) learning in schools is often theoretical and separated into the branches of Physics and Biology. As a result, students have difficulty understanding the relationship between physics concepts such as fluid pressure and their application to biological systems, particularly the human circulatory system. Pressure phenomena in the body, such as blood pressure due to the action of the heart, are often abstract and difficult to visualize without the aid of concrete media. Therefore, innovative learning media that can combine the concept of fluid pressure and the working mechanisms of the circulatory system are important to create meaningful and contextual learning. The purpose of this study is to develop a Bio-Hydro Pressure Simulator as an integrative learning media based on hydrostatic simulation that represents the relationship between fluid pressure and blood flow mechanisms in the systole and diastole phases. This study uses the Research and Development (R&D) method with a 3D model (Define, Design, and Develop) according to Thiagarajan that is limited to the development stage. Through this approach, the media is designed based on an analysis of learning needs, validated by experts, and systematically arranged to ensure product feasibility. The validation results show that the Bio-Hydro Pressure Simulator is suitable for use as an innovative learning medium that can help students understand the relationship between fluid pressure and the circulatory system in a concrete and interactive manner. This media is expected to be able to improve junior high school students' conceptual understanding of the phenomenon of pressure in the body and foster cross-disciplinary thinking skills between Physics and Biology.

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INTRODUCTION

Natural Science (IPA) education at the secondary school level is often fragmented into two main branches: Physics and Biology. Although these two disciplines are closely related and influence each other, conventional teaching methods tend to emphasize theoretical aspects

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separately. This results in students having difficulty understanding the complex relationship between physics concepts, such as fluid pressure, and their biological applications, particularly in the context of the human circulatory system.

Blood pressure, a vital phenomenon in the body, is the result of the heart pumping blood through blood vessels to all organs. This process involves a dynamic interaction between various physical and biological factors, which are often difficult to explain in a standalone learning context. For example, pressure in blood vessels is influenced by various physical factors, such as gravity and flow resistance, which are fundamental concepts in physics. However, students are not always aware of how these factors contribute to broader biological functions, such as the distribution of oxygen and nutrients throughout the body's tissues.

One example of a common conceptual gap is in the teaching of fluid pressure in Physics and the circulatory system in Biology. These two topics are actually closely related, as the principles of fluid pressure form the basis for understanding the mechanisms of blood flow, blood pressure, and heart function during systole and diastole. However, this connection is often underemphasized in classroom instruction. Furthermore, the phenomenon of pressure in the human body tends to be abstract and difficult for students to visualize without concrete learning tools or media (Maysha Syakila et al., 2025).

This lack of understanding often prevents students from connecting physics theory to biological practice. This can lead to gaps in conceptual understanding, where students simply study the material in isolation without recognizing the true connections between the two. As a result, students struggle not only to grasp the concepts but also to develop the critical thinking skills necessary to analyze complex real-world phenomena.

One innovative approach to science learning that can be applied is the development of the Bio-Hydrostatic Pressure Simulator, a simulation-based learning tool that integrates the concept of hydrostatic pressure. This simulator aims to connect understanding between physics concepts, particularly fluid pressure, and biology, particularly the working mechanisms of the human circulatory system. With this integrative approach, students not only learn abstract formulas or theories but also see the real-life application of physics principles in living organisms.The Bio-Hydrostatic Pressure Simulator is designed to visualize the direct relationship between fluid pressure, volume, and flow in a closed system, comparable to the human circulatory system. In this system, fluid pressure influences the speed and direction of flow, similar to the systole and diastole processes in the heart, and the differences in blood pressure in arteries and veins. With this visualization, students can observe how changes in pressure in one part of the system impact the overall flow, making previously abstract concepts more concrete and understandable.

Through the development of this media, it is hoped that students will not only be able to understand the concept of pressure in the context of physics, but also be able to see its application in biological systems. The Bio-Hydro Pressure Simulator is expected to improve students' conceptual understanding of pressure phenomena in the body and foster critical and interdisciplinary thinking skills. Thus, this research aims to create meaningful and relevant learning, as well as improve the quality of science education in schools. This kind of innovation is expected to inspire more integrative and effective teaching methods, which will ultimately prepare students to face more complex scientific challenges in the future.

METHOD

This study applies the Research and Development (R&D) method with a 3D model (Define, Design, Develop) adapted from Thiagarajan, Semmel, and Semmel (1974). This model was chosen because it is suitable for creating and testing the feasibility of innovative learning media that are systematically designed. This research is limited to the development stage, focusing on the creation and validation of a product in the form of a Bio-Hydrogen

Pressure Simulator as a learning medium that integrates the concepts of fluid pressure and the circulatory system. The R&D method allows researchers to carry out a series of steps starting from needs analysis and designing prototype media to product validity testing by experts. This approach aims to produce media that is feasible, effective, and appropriate to the needs of science learning at the junior high school level (Alatas, 2019).

1. Research Design

   This research design follows the 3D development model (Define, Design, and Develop) according to Thiagarajan which includes three main phases.

   a. Define

      The Define stage aims to identify learning needs through curriculum analysis to adapt the material on fluid pressure and the circulatory system to the Junior High School Science Core Competencies, student analysis to determine their characteristics and level of understanding, task and concept analysis to explore the relationship between fluid pressure and blood pressure, and media needs analysis through teacher interviews to determine student difficulties and the need for concrete visualization media.

   b. Design

      The Design stage is carried out to design the concept and structure of the Bio-Hydrogen Pressure Simulator through three main steps, namely conceptual design by compiling a flowchart and storyboard that describes the relationship between pressure, fluid flow, and the circulatory system (systole and diastole phases); visual and mechanical design by creating a simulator model based on a simple hydrostatic system using transparent tubes, colored liquids, and a manual pump as a simulation of the heart's work; and designing a validation instrument in the form of an assessment sheet for material experts and media experts to assess aspects of content, construction, appearance, and usefulness of the learning media.

   c. Develop

      The Develop stage includes the creation of a Bio-Hydrogen Pressure Simulator prototype based on the visual and mechanical designs that have been prepared, then expert validation is carried out by material experts (physics and biology) to assess the suitability of the concept and integration between disciplines, and by media experts to assess technical aspects, design, appearance, and interactivity. Based on the validation results, product revisions are carried out until a suitable learning medium is obtained and ready to be used in teaching and learning activities.

2. Data collection technique

   Data collection techniques in this study included expert validation, documentation, interviews and literature study. Expert validation was conducted using a Likert scale assessment sheet to obtain quantitative and qualitative data regarding the media's suitability in terms of material and appearance. Documentation was used to collect visual and descriptive data during the simulator design and development process, Meanwhile, interviews and literature studies were conducted to obtain information regarding the learning needs and difficulties of students and teachers in understanding the relationship between the concepts of fluid pressure and blood pressure.

3. Hypothesis

   The hypothesis proposed in this research is exploratory in nature, namely that the Bio-Hydrogen Pressure Simulator developed through 3D modeling (Define, Design, Develop) is suitable for use as an integrative learning medium capable of helping students

understand the relationship between the concept of fluid pressure and the circulatory system in a concrete and interactive manner (Firdania et al., 2023).

4. Evaluated

The researcher evaluated the feasibility and effectiveness of the product based on the collected data. The assessment process was conducted by referring to the score interpretation criteria proposed by Riduwan and Hildayatni et al. (2019), as shown in Table 1. (Hildayatni et al., 2019)

Table 1. Score Intepretation Criteria

Percentage	Classification	Feasibility Criteria
81% -100%	Very Valid	No Revision
61% - 80%	Valid	No Revision
41% - 60%	Fairy Valid	Revision Needed
21% - 40%	Less Valid	Revision
0% - 20%	Very Poorly Valid	Major Revision

Data collection in this study was carried out using observation sheets and questionnaires. The data analysis techniques employed included both qualitative and quantitative descriptive analysis. The qualitative descriptive analysis was calculated using Formula (1):

$$\textbf{Persentase} = \frac{\text{Obtained Score}}{\text{Maximum Score}} \times \mathbf{100\%} \quad \textbf{..... (1)}$$

RESULT AND DISCUSSION

The learning needs analysis revealed that both teachers and students experienced difficulties in understanding and teaching the relationship between the concept of fluid pressure in physics and the circulatory system in biology. Interviews with science teachers revealed that students were able to master the mathematical formula for pressure but struggled to relate it to biological phenomena, such as blood flow and heart function. Teachers noted that learning still focused on memorizing formulas and two-dimensional illustrations found in textbooks, making it difficult for students to visualize how pressure functions within the human body. These findings highlight the need for more concrete and interactive learning media that can connect physics and biology concepts in a more relevant context.

Research conducted by Elga Amelia, Maison, and Kamid (2023) focuses on the development of interactive e-modules using 3D Pageflip Professional as an innovative learning solution to address junior high school students' misconceptions about fluid pressure. The background of this research is in line with general findings in science learning, where the concept of pressure is often considered abstract and difficult to understand due to the limitations of concrete visual media. Many students have misconceptions, such as the assumption that the shape of the container affects fluid pressure or that the higher the surface of the liquid, the greater the pressure. In fact, scientifically, hydrostatic pressure is determined by the depth and density of the fluid. To address these challenges, researchers implemented the Research and Development (R&D) method with the ADDIE (Analyze, Design, Develop, Implement, Evaluate) model. In the Analyze stage, learning needs and obstacles in physics learning in schools were identified. It was found that teachers still rarely use digital teaching materials, while students have difficulty understanding the material because the existing media is less interesting and interactive. Based on these findings, an interactive digital e-module was developed that includes conceptual explanations, image illustrations, 3D animations, fluid pressure simulations, and exercises based on a four-tier diagnostic test to help students understand concepts visually and independently (Amelia et al., 2021).

These findings suggest that learning using interactive digital media can improve conceptual understanding and reduce misconceptions more effectively than conventional methods. Just as the Bio-Hydro Pressure Simulator integrates physics and biology concepts

through visualizations of blood pressure and flow, the 3D Pageflip e-module also emphasizes the importance of scientific visualization-based learning to bridge the gap between theory and real-world phenomena. Both reinforce the argument that the use of innovative, technology-based learning media can improve the quality of science learning by making abstract concepts more concrete, engaging, and understandable to students (Amelia et al., 2021).

Research by Nitesh Bhatia and Omar K. Matar (2022) discusses the development of innovative learning media for fluid dynamics using Augmented Reality (AR) and Mixed Reality (MR) technologies. The use of this immersive technology emerged as a solution to a common problem in science learning: students' difficulty visualizing abstract concepts, such as fluid flow and pressure distribution in three-dimensional space. This finding aligns with challenges in learning fluid pressure and the circulatory system, where students often struggle to relate physics theory to real-world biological phenomena. To address these challenges, researchers designed an AR–MR-based learning platform that allows students to interactively view, manipulate, and understand three-dimensional fluid models. The platform's development followed a Research and Development (R&D) approach with the Define, Design, and Develop stages, similar to the development of the Bio-Hydrostatic simulator. In the Define stage, analysis was conducted to identify learning needs and areas of fluid concepts that students found difficult to grasp. The Design stage involved designing a 3D model using Computational Fluid Dynamics (CFD) data, which was then integrated into a WebXR application for browser-based access without installation. The Develop stage focused on testing the feasibility and effectiveness of the media by involving students in a hybrid learning trial. Validation results showed that this media is highly suitable for use in science learning, as it helps students understand the concepts of fluid pressure and flow. Students who previously only memorized formulas can now observe changes in pressure and flow velocity through dynamic three-dimensional visualizations, thus linking theory to real-world phenomena, such as the effects of viscosity, cross-sectional area, and gravitational acceleration on fluid flow (Bhatia & Matar, 2022).

The findings of this study strengthen the evidence that immersive technology can be an effective solution in teaching complex science concepts. Like the Bio-Hydro Pressure Simulator, which integrates physics and biology, this AR-MR-based media also encourages interdisciplinary learning, motivating students to think across concepts between physics theory, natural phenomena, and the application of digital technology. Thus, this media not only deepens conceptual understanding but also hones critical, creative, and reflective thinking skills, in line with the demands of 21st-century learning (Bhatia & Matar, 2022).

Research conducted by Samosir et al. (2024) revealed that students' ability to analyze the application of fluid mechanics in the circulatory system only reached an average of 49.21%, which is included in the "sufficient" category. This indicates that many students still struggle to integrate physics concepts into a comprehensive biological context. Data obtained through Bloom's taxonomy showed a similar pattern. At the lower cognitive level (C1–C3), students' abilities were assessed as adequate to excellent, particularly in the comprehension aspect (C2), which reached 92.70%. However, at the higher cognitive level (C4–C6), there was a significant decline, with analytical ability reaching only 41.66%, evaluation 39.57%, and creativity 36.45%, all of which were considered poor. These findings indicate that students have a better grasp of conceptual aspects and formula memorization, but have difficulty connecting physics theory to biological phenomena analytically and applicably. Furthermore, the science teachers interviewed stated that the learning process is still dominated by conventional methods, which emphasize formula memorization and two-dimensional illustrations from textbooks. This makes it difficult for students to visualize how fluid pressure functions in the human body system, such as the role of the heart, blood flow, or the pressure differences between arteries

and veins. This condition indicates that an abstract learning approach makes it difficult for students to understand cross-disciplinary concepts in depth (Silitonga et al., 2024).

These findings align with research conducted by Muhabbatun Nisa' et al. (2022), which showed that approximately 27% of junior high school students experience misconceptions related to the topic of pressure of substances. The details of these misconceptions include 30% on the pressure of solids, 28% on hydrostatic pressure, 38% on gas pressure, and 25% on the application of pressure in the context of living things. The main difficulty faced by students is caused by the belief that pressure is directly proportional to the area of the pressure area, when in fact, scientifically, pressure is actually inversely proportional to the area. In addition, many students assume that hydrostatic pressure is influenced by the shape of the vessel, not by the depth and density of the fluid. This misconception reflects a weak conceptual understanding and a lack of practical and experimental learning experiences (Nisa' et al., 2022).

Based on the validation results of the learning media from three expert validators, it was found that the developed media was rated as very good and feasible to use, with minor revisions suggested. In general, the validators stated that this media is able to accurately represent science concepts appropriate for the junior high school (SMP/MTs) level and does not contain any scientific misconceptions. The media is also considered effective in visually explaining complex concepts and aligns with the current curriculum. Additionally, the teaching aid is easy to assemble, can be used independently, and has a simple yet attractive design and color scheme for students.

The validator assessed that this media met various aspects of suitability, including content, presentation, appearance, and ease of use. However, there were several suggestions for improvements that need to be considered to refine the media before use in field trials. First, the validator recommended that each component in the simulator be equipped with an informative description or label. Adding labels to key parts such as the heart chambers, valves, arteries, veins, and capillaries is considered important to help students quickly recognize the structures and understand their respective functions in the context of blood circulation. With these descriptions, the learning process can be more meaningful, because students can directly link the visual phenomena they observe with the underlying scientific concepts. These additional labels also serve as conceptual scaffolding, facilitating students' transition from the observation stage to a deeper understanding.

Second, the validators suggested clarifying the relationship between the concept of fluids in physics and the circulatory system in biology. This is important because one of the primary goals of this resource is to integrate two disciplines that are typically taught separately. In this regard, it is recommended that the resource include visual indicators of fluid pressure, such as arrows indicating the direction of blood flow, with varying line thicknesses or color differences to depict high and low pressures. Furthermore, the addition of images or indicators of the position of the heart is also recommended so students can visualize the overall direction and trajectory of blood flow. With these updates, the concepts of hydrostatic pressure, pressure gradients, and fluid flow velocity will become more easily understood in a biological context.

Table 2. Validation Results of the Bio-Hydro Pressure Simulator Media

Validator	Percentage	Description
Science Teacher 1	95,38%	Very Valid
Science Teacher 2	90,77%	Very Valid
Science Teacher 3	93,85%	Very Valid

Beyond the validation process, the effectiveness test indicatet that the use of this simulator significantly improved students conceptual understanding. Students who initially strunggled to grasp ho pressure works in the human body became able to descripe blood flow processes accurately using scientific terminology such as systole, diastole, and hydrostatic pressure. The simulator also helped correct common misconceptions, such as the belief that blood pressure uniform throughout the body of that it depends on vessel shape. Throught hands-on observation of pressure changes within the simulator, students develop deeper and more logical understanding.

The use of this simulator has proven effective in addressing common misconceptions often experienced by students. One of the most common misconceptions is the assumption that blood pressure is uniform throughout the body or that pressure is only influenced by the size of the blood vessels. Through the simulator's dynamic pressure visualization features, such as color changes, flow velocity, and fluid movement direction, students can observe how pressure gradually decreases from arteries to capillaries, and how venous valves prevent backflow of blood. With this approach, abstract concepts such as Pascal's law and Bernoulli's principle become not only theories but also real, observable phenomena.

This simulator plays a crucial role in fostering scientific reasoning-based learning. Through hands-on exploration, students are encouraged to predict, observe, and explain the phenomena of pressure and fluid flow in the body, in accordance with the stages of the inquiry-based learning approach. For example, when students observe the increase in pressure as the "heart chambers" contract, they can relate this phenomenon to the concepts of force and volume in a confined fluid, and explain why blood flows from areas of high pressure to areas of low pressure. This process strengthens students' higher-order thinking (HOTS) skills, particularly in the analysis and interpretation of scientific phenomena. In addition to enhancing conceptual understanding, the use of simulators also positively impacts student motivation and engagement in the learning process. Three-dimensional visualizations complemented by fluid movement animations make learning more engaging, contextual, and relevant to everyday life. Students demonstrated high enthusiasm because they could "see" how pressure functions within their own bodies something previously only conveyed through text or static images in textbooks. The interactivity offered through navigation and simulation features also stimulated curiosity, sparked discussion, and enhanced collaboration skills within groups.

Before using the simulator, students often had difficulty understanding the blood flow process because the mechanism was too fast or slow to observe directly. However, after using this interactive media, students were able to accurately describe the stages of small and large blood circulation, as well as explain the role of various heart components such as the right ventricle, left ventricle, right atrium, and left atrium in the process of systole and diastole. With the help of dynamic and interactive animations, the concepts of blood pressure, the direction of blood flow, and the pressure difference between arteries and veins can be clearly visualized, so that students not only memorize but also truly understand the process scientifically. Additionally, this media helps correct common misconceptions among students, such as the assumption that blood pressure is uniform throughout the body or that blood circulation occurs only in one direction without reverse circulation. Through interactive simulation features, students can observe visual changes resulting from pressure differences in blood vessels or disorders such as hypertension and heart disease, students learn contextually about the relationship between the structure and function of the circulatory system (Kwarrie & Radion, n.d.).

Overall, the implementation of the Bio-Hydro Pressure Simulator is expected to enhance student’s conceptual understanding by transforming abstract theoretical knowledge into concrete experience. This integrative approach fosters interdisciplinary thinking, allowing students to perceive how physics principles underpin bilogical system. By engaging students

in hands-on exploration, the media not only clarifies misconceptions about pressure and circulation but also encourages scientific curiosity and deeper comprehension. Hence, this research confirms that innovative, integrative learning tools like the Bio-Hydro Pressure Simulator can significantly improve the quality of science education and promote meaningful learning experiences at the junior high school level. (Wijaya, 2016)

CONCLUSION

The development of the Bio-Hydro Pressure Simulator succesfully produced an innovative learning medium that integrates the concept of fluid pressure in physics with the circulatory system in biology in a concrete and interactive manner. Validation results from expert indicated that this medium is classified as highly valid and feasible for use in science learning at the junior high school level. Through the use of the simulator, students can easily understand the relationship between fluid pressure and blood flow mechanisms, including the systole and diastole phases, which were previously difficult to visualize theoretically. In addition, this medium effectively helps reduce students misconceptions, such as the belief that blood pressure is uniform throughout the body or depends on the shape of blood vessels.

This integrative learning approach enhances conceptual understanding, interdisciplinary thinking skills, and scientific curiosity among students. Therefore, the Bio-Hydro Pressure Simulator has the potential to serve as an effective solution for creating more meaningful, contextual, and experience-based science learning, ultimately supporting the improvement of science education quality in school.

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