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Artikel

Biosonic Ear Model: Integrated Science Learning Innovation for Sound Wave and Hearing System Learning in Support of Sustainable Education

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ABSTRACT

The digital era 5.0 demands education to transform towards innovative, interactive, and interdisciplinary learning. In science education, the physics concept of sound waves and the biological hearing system are often taught separately, which hinders students' understanding of the relationship between the two. Limited contextual and engaging media hinder teachers in explaining scientific processes in an integrated manner. This study developed the Biosonic Ear Model as an integrated science medium that combines the concepts of sound waves and the auditory system to enhance student engagement. Using Research and Development (R&D) through the Thiagarajan 3D model (define, design, develop), feasibility assessment was conducted by media experts and subject matter experts using validation sheets, with quantitative and qualitative descriptive data analysis. The results showed a validation score of 4.30, categorized as “very good” (4.21–5.00). Thus, the Biosonic Ear Model is considered suitable for science learning in schools. The development of this media has a positive impact in the form of increased interdisciplinary understanding and active student participation. In addition, this media is recommended for implementation by teachers in integrated science learning, and further studies on its effectiveness at various levels of education are needed.

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INTRODUCTION

Education in the digital era 5.0 requires significant transformation in the learning process to become more innovative, interactive, and interdisciplinary. The concept of Society 5.0, which is beginning to be applied in the field of education, shows that learning systems cannot rely solely on conventional methods but must utilize digital technology, provide collaborative learning experiences, and encourage the development of digital literacy and 21st-century skills. For example, research shows that education must be able to adapt to the demands of an era in which humans and technology collaborate for the sake of superior human resources (Rahmadani et al., 2024). However, in reality, in the context of science learning in secondary schools, learning is still linear and fragmented across disciplines.

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In science education in schools, particularly in Natural Sciences (IPA) material in grade VIII, which involving physics concepts such as sound waves and biology concepts such as the human auditory system, these two concepts are often taught separately without emphasizing the functional relationship between them. This situation makes it difficult for students to understand how physical phenomena (sound waves) interact with biological mechanisms (the auditory system), thus limiting their holistic understanding. In addition, the limited availability of contextual and engaging learning media further hinders teachers in explaining scientific processes in an integrated manner. A study on the development of context-based teaching materials on sound waves shows that such media are urgently needed because conventional teaching materials are insufficient in promoting deep understanding among students (Yunus & Syarif, 2024).

Efforts to integrate the concept of sound waves in physics with the human auditory system in biology remain a challenge in science education. The learning process often stops at separate conceptual understanding of the two fields without giving students the opportunity to explore the scientific relationship that underlies them. Learning media that not only displays scientific processes visually but also provides contextual and interactive learning experiences is needed so that students can more easily understand the relationship between physical phenomena and the biological mechanisms of hearing. Previous studies have shown that the development of interactive media based on the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach on sound and the human auditory system can increase student interest and engagement because it presents concrete visual simulations of the hearing process (Ukhriyah & Suryanti, 2024). Additionally, interactive e-modules and contextual teaching aids have also been proven effective in deepening students' conceptual understanding of sound and its application in the human body (Permatasari et al., 2021). Therefore, developing learning media that combines physics and biology in an engaging and easy-to-understand manner is an important step toward enhancing student engagement and science literacy in the era of digital learning 5.0.

Learning media are all forms of physical and non-physical tools, materials, or means used to convey messages and facilitate the learning process so that students can acquire knowledge, skills, and attitudes more effectively (Amka, 2018). The presence of media serves as an intermediary between teachers and students in concretizing abstract concepts, especially in science learning that involves processes and phenomena that cannot be observed directly. According to Sadiman et al. (2014), learning media not only acts as a tool, but also as an integral component in the learning system that can stimulate students' interest, attention, and active participation. In the context of science learning, the use of contextual and interactive media is very important to help students understand the interrelationships between concepts and apply the knowledge gained in real-life situations.

Research at the junior high school level shows that an interdisciplinary approach to science education plays an important role in building comprehensive and meaningful conceptual understanding among students. Taihuttu et al. (2023) argue that the application of the Science-Technology-Society learning method significantly improves student learning outcomes in the subjects of vibration, waves, and sound at SMP Negeri 3 Tondano. The application of this approach is able to link scientific concepts with their application in everyday life, making learning more contextual and relevant. On the other hand, developments in educational technology have also encouraged the use of interactive learning media based on three-dimensional (3D) visualization to increase student motivation and understanding. Purnomo et al. (2023) developed 3D-based interactive media on vibration, waves, and sound for eighth-grade junior high school students, which proved to help students understand the structure of the material visually, attractively, and easily. However, research that explicitly integrates the concept of sound waves in physics with the auditory system in

biology into a single integrated learning medium is still very limited. Fitri et al. (2021) have examined the use of organ pipes as an effective learning medium for sound waves that improves understanding of physics concepts, but the integration of aspects of the human auditory system in biology into this medium has not been widely explored. The development of 3D visual model-based learning media that integrates physics and biology concepts is an important step to strengthen interdisciplinary learning and support increased moti vation and learning outcomes for junior high school students.

Previous research findings indicate that eighth-grade junior high school students' conceptual understanding of vibrations and waves is still relatively low. Christiani, Munzil, and Yulianti (2021) reported that approximately 54.94% of students had misconceptions about wave motion, and only a small proportion truly understood the concept scientifically. This situation confirms that in the Education 5.0 era, despite the rapid development of technology and information, students' conceptual understanding of basic scientific phenomena remains a major challenge in science learning.

Based on this description, the main challenge in science education at the secondary school level is how to integrate the concept of sound waves in physics with the human auditory system in biology into a single contextual and interesting learning unit. Learning that is still conducted separately results in low student understanding of concepts and integrative thinking skills regarding the relationship between physical phenomena and biological processes. In addition, the available learning media generally only present theoretical aspects without providing concrete visualizations of the relationship between the two concepts.

In response to these needs, this study developed and validate the Biosonic Ear Model as a contextual learning medium that bridges the concepts of sound waves (physics) and the auditory system (biology) into a single integrated science learning unit. This medium is designed to present realistic visualizations of scientific processes through a cross-disciplinary approach, enabling students to understand the relationship between physical phenomena and biological processes in concrete terms. The development was carried out using Thiagarajan's 3D Research and Development (R&D) model, which consists of three main stages, namely define, design, and develop. The definition stage involved analyzing the needs of students and teachers, the design stage produced a preliminary design for an integrative model, and the development stage was carried out through expert validation of the material and media using quantitative and qualitative descriptive analysis. This approach offers innovative learning solutions that support sustainable education in the digital 5.0 era.

The innovation of this research lies in combining two disciplines, namely physics and biology, into a contextual and applicable learning model. Unlike previous studies that discussed the two separately, the Biosonic Ear Model integrates both concepts into a single complementary medium, thereby helping students understand the scientific relationship between sound waves and the human hearing mechanism as a whole. In line with Puspita et al. (2013), integrated science learning with a contextual approach has been proven to increase student activity and learning outcomes. Furthermore, the Biosonic Ear Model not only displays the anatomy of the ear visually, but also visualizes the propagation of sound waves interactively. The novelty of this media also lies in the use of the Sound Meter application as a digital tool to measure sound intensity directly, allowing students to observe the relationship between sound intensity and the process of wave reception by the ear. The integration of this simple technology strengthens the real-world experimental learning experience while fostering students' digital literacy. These advantages make this medium different from digital media or single animations. While the research by Rizkiyani et al. (2024) and Nurdiyanti et al. (2022) shows that the use of e-modules and the Moodle Learning Management System (LMS) increases student engagement in the topic of sound, the Biosonic Ear Model presents a more comprehensive innovation through a combination of digital,

experiential, and real learning experiences. Thus, this study not only focuses on developing an instructional medium but also aims to address students' conceptual gaps identified in previous studies. This medium supports the Education 5.0 paradigm and sustainable education through integrated science learning that fosters scientific and ecological awareness, as well as 21st-century technological literacy.

METHODS

This study used the Research and Development (R&D) method with Thiagarajan's 4D development model, which was later modified into a 3D model consisting of three main stages: defining, designing, and developing. This model was chosen because it is suitable for producing and testing the feasibility of innovative and applicable educational products, in this case the Biosonic Ear Model as an integrated science learning medium (Jannah & Hidayat, 2022). The specified stages include the process of collecting data from various sources to identify learning needs, student difficulties, and actual conditions in the field as a basis for product development. The design stage includes the development of a learning media model that integrates the concepts of sound waves and the human auditory system visually and interactively. The next stage of development is carried out by developing and validating the product through assessments by one subject matter expert and two media experts, namely science teachers (Rahmi & Bahruddin, 2021).

The media expert validation instrument includes six components: suitability, durability, accuracy, efficiency, aesthetics, and student safety. Meanwhile, the material expert validation instrument consists of four components: suitability, completeness, ease of use, and conceptual clarity. Then the validation data is analyzed descriptively quantitatively and qualitatively to determine the level of feasibility of the product developed before being implemented in learning (Agung, 2017). This method was chosen to ensure the developed media could be systematically validated in terms of content, design, and pedagogical effectiveness.

Averange rating per validator

$$Final\ Score = \frac{\sum score\ obtained}{\sum item}$$

Final value of validation test

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

The eligibility criteria for media instruments are as follows:

Table 1. Media Eligibility Criteria Score

Score Interval	Category
4.21-X-5.00	Very Good
3.41-X-4.20	Good
2.61-X-3.40	Enough
1.81-X-2.60	Not Enough
1.00-X-1.80	Very Less

(Umar, 2011)

RESULTS AND DISCUSSION

The results of this study were obtained through a predetermined method, namely by adopting Thiagarajan's 3D development model, which consists of three main stages: define, design, and development. Each stage was carried out systematically to produce learning media that suited the needs of students and the objectives of integrated science learning. Through these stages, the development of the Biosonic Ear Model focused on creating media

that is not only scientifically accurate, but also interesting, easy to use, and relevant to the context of 21st-century learning.

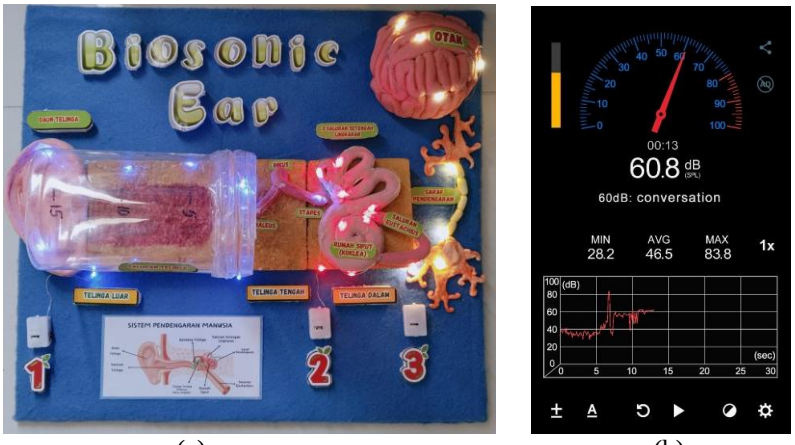
Define Phase

The definition stage aims to identify the needs, problems, and initial learning conditions in the material on sound waves and the auditory system, which form the basis for the development of the Biosonic Ear Model. Initial analysis shows that the science learning process in grade VIII of junior high schools is still dominated by lecture methods and the use of textbooks without the support of contextual visual media. This condition causes students to have difficulty understanding the relationship between the physics concept of sound waves and the biological function of the human auditory system. These findings are in line with the research by Oktavia and Saehana (2024), which states that teachers have not optimally utilized interactive learning media in sound wave material, making learning less interesting and resulting in low motivation and learning outcomes for students.

Based on the needs analysis, there is a need to develop innovative learning media that can integrate physics and biology concepts through concrete, visual, and interactive learning experiences. The STEAM-based approach as applied in the research by Oktavia and Saehana (2024) has been proven to increase student engagement and understanding through a combination of science and creativity. Therefore, the Biosonic Ear Model was designed as a three-dimensional medium that displays the structure of the human ear as well as the mechanism of sound wave propagation, so that students can visualize the entire hearing process. This medium is expected to bridge the gap between theory and practice, foster critical thinking skills, and support integrated science learning oriented towards sustainable education.

Design Phase

The Biosonic Ear Model is an innovative learning medium that integrates physics and biology material in a concrete and visual manner. The Biosonic Ear Model is designed in three dimensions using clay molded to resemble the ear organ, including the ear lobe, ear canal, auditory bone, cochlea, auditory nerve, and brain. This allows students to clearly recognize the structure and function of the human ear.



(a) (b)

Figure 1. A) Biosonic Ear Model Learning Media, B) Sound Meter Application

The uniqueness of this model lies in the use of different colored lights for each stage of the hearing process. The lights are installed along the sound wave path from the outer ear to the middle ear, inner ear, and brain. During the demonstration, the lights turn on sequentially in accordance with the sound propagation process, allowing students to visualize the flow and

mechanism of hearing in a regular and dynamic manner. The use of colorful lights is designed to make it easier for students to distinguish and understand the stages of the hearing process while increasing the appeal of learning. In addition, this model integrates physics through the simulation of sound waves using plastic bottles as an analogy for the ear canal. A plastic piece and a spring are placed at the end of the bottle to function as the eardrum.

When a sound source is inserted into a bottle, the sound waves vibrate the plastic and spring at the end of the bottle, demonstrating the mechanism of sound vibration reception and transmission in the human ear in real time. In using this learning media, the Sound Meter application on a smartphone device is also utilized to measure the sound intensity from various sound sources tested. The results of research by Lidya and Habibah, (2023) show that the Sound Meter application on a smartphone has a fairly high level of accuracy and precision in detecting sound frequencies, with the results of sound velocity measurements in air approaching the theoretical value of 340 m/s. These findings strengthen the case that sound sensor-based applications on mobile phones can replace the function of conventional laboratory equipment such as Sound Level Meters (SLM), especially in schools with limited practical facilities.

Through sound intensity measurement activities using this application, students can directly observe variations in sound strength from various sources in the surrounding environment, such as vehicle noise, music, or conversations, while also understanding how the human ear responds to sounds of different intensities. The use of the Sound Meter application also raises students' awareness of the importance of maintaining healthy hearing from exposure to high-intensity sounds that can damage the ears. Thus, the integration of simple smartphone-based technology in science learning media not only enriches the experimental learning experience but also fosters scientific attitudes and environmental awareness in students.

This media design integrates biology and physics material into a single interactive model, in line with the STEAM approach that emphasizes the integration of science and creativity to support active learning, critical thinking, and increase student motivation in learning. Through exploration and practical demonstrations, students can analyze and discuss the structure, function, and mechanism of the auditory system and its relationship to the principles of sound waves (Setyaningsih et al., 2022). With its comprehensive and user-friendly design, the Biosonic Ear Model is expected to strengthen conceptual understanding and increase student engagement in integrated and contextual science learning.

Develop Phase

The Biosonic Ear Model learning media then underwent a feasibility test to ensure that the media developed was suitable for use in the learning and teaching process. The validation process was carried out by several validators who assessed the level of suitability of the media and the accuracy of the material presented. The validators involved consisted of two media experts and one material expert. In the validation activity, the researchers showed the Biosonic Ear Model learning media and explained its functions to the validators, accompanied by an assessment instrument in the form of a validation sheet. After the validation questionnaire was filled out by the experts, the next step was to process the assessment data. The data from the validation sheets of the media and material experts is then converted into quantitative form through percentage calculations. In addition, the validation results also include comments, input, and product revision suggestions from the experts, which are described in detail for use in improving the learning media. The following are the assessment results from two media experts which are shown in Table 2.

Table 2. Media expert validation results

Aspect	Validator 1	Validator 2	Average	Category
Suitability	4.00	4.67	4.33	Very Good
Durability	3.33	3.33	3.33	Enough
Accuracy	4.00	5.00	4.50	Very Good
Efficiency	3.67	4.67	4.17	Good
Easthetics	4.00	4.00	4.00	Good
Safety	4.00	4.00	4.00	Good
Average final result			**4.06**	**Good**

To facilitate the validation of the Biosonic Ear Model learning media, the data in the assessment results table from the two validators was then converted into a bar chart. This chart depicts the average score for each assessment aspect, including suitability, durability, accuracy, efficiency, aesthetics, and safety.

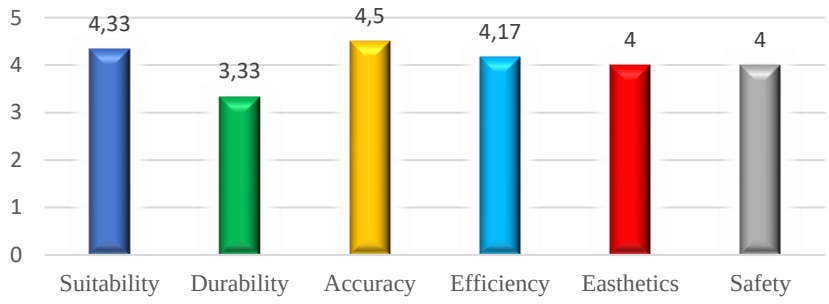


Figure 2. Bar diagram of validation results by media experts

Based on the validation results by two media experts, there are six assessment indicators, namely suitability, durability, accuracy, efficiency, aesthetics, and safety. For the suitability indicator, an average score of 4.33 was obtained, which is in the very good category, indicating that the media is suitable for the learning objectives and content. The durability indicator received an average score of 3.33, which is in the fairly good category, meaning that the durability of the media needs to be slightly improved for optimal long-term use. Furthermore, the accuracy indicator received the highest average score of 4.5, which is in the excellent category, indicating that the media presents accurate and relevant information and concepts. The efficiency indicator received an average score of 4.17, which is in the good category, indicating that the media is easy to use and supports the effectiveness of the learning process. For the aesthetics indicator, the average score obtained was 4, which is in the good category, indicating that the media's appearance is attractive and suitable for the characteristics of the students. Meanwhile, the safety indicator also received an average score of 4, which is in the good category, indicating that the media is safe to use without posing a risk to users. Overall, the results of the media expert validation showed an average score of 4.06, which is in the good category. Thus, the developed media is deemed suitable for use in learning activities, with recommendations for improvements in terms of durability to maximize the quality of the media.

Next, the validation results from the material experts were analyzed to assess the appropriateness of the content and the accuracy of the concepts presented in the Biosonic Ear Model learning media. The assessment results from the material experts were presented in a table containing the average score for each assessment aspect, thus illustrating the extent to which the material in this media aligns with the curriculum and student characteristics. The following data shows the average score from the validation results from the material experts, shown in Table 3.

Table 3. Meterial expert validation results

Aspect	ΣScore Obtained	ΣItem	Final Score	Category
Suitability	14	3	4.67	Very Good
Completeness	14	3	4.67	Very Good
Ease of use	13	3	4.33	Very Good
Clarity	9	2	4.50	Very Good
Average final result			**4.54**	**Very Good**

To facilitate the reading of the expert validation results for the Biosonic Ear Model learning media, the data in the assessment results table was then converted into a bar chart. This chart depicts the average scores for four assessment aspects: material suitability, conceptual depth, scientific accuracy, and integration with the learning objectives.

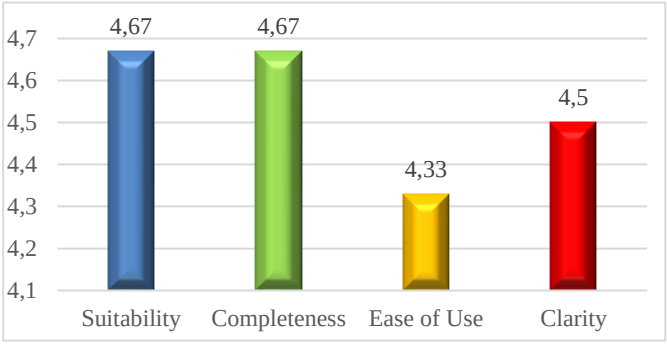


Figure 3. Bar diagram of validation results by material expert

Furthermore, based on the validation results by subject matter experts, there are four assessment indicators, namely suitability, completeness, ease of use, and clarity. For the suitability indicator, an average score of 4.67 was obtained, which is classified as very good, indicating that the material presented is in line with the learning outcomes and learning objectives. The completeness indicator also received an average score of 4.67, which is in the excellent category, meaning that the material covers all important components and supports the achievement of learning objectives as a whole. Furthermore, the ease indicator received an average score of 4.33, which is in the good category, indicating that the material is easy for students to understand, although it still needs some refinement in terms of presentation to make it simpler and more communicative. The clarity indicator received an average score of 4.5, which is categorized as very good, indicating that the material explanations have been systematically organized, clear, and easy for users to follow. Overall, the results of the material expert validation showed an average score of 4.54, which is categorized as very good. Thus, the developed material is deemed highly suitable for use in learning activities, with a suggestion to slightly improve its ease of use to optimize student understanding. Based on validation by three validators, namely two media experts and one subject matter expert, the average validation score was 4.3, which is considered excellent.

The validation results, which obtained an average score of 4.30 categorized as very good, indicate that the Biosonic Ear Model fulfills the criteria of feasibility, clarity, and practicality as an integrated learning medium. This finding confirms that the developed media aligns with the essential characteristics of effective instructional tools described by Sadiman et al. (2014), which emphasize the importance of stimulating students' attention and translating abstract scientific concepts into tangible learning experiences. The high validation score also demonstrates that the media's visual, interactive, and contextual elements successfully meet the learning needs identified during the Define Phase.

Based on the validation results conducted by media experts and subject matter experts on the development of the Biosonic Ear Model learning media, it was assessed that this media has met the eligibility criteria in terms of both visual appearance and material accuracy. In

general, the media is considered attractive, interactive, and effective in helping students understand the concepts of sound waves and the human auditory system through an experimental approach and three-dimensional visualization. The main innovation of this media lies in the use of the Sound Meter application on a smartphone to measure the sound intensity of various sound sources that are tested. Through this activity, students not only made qualitative observations of sound phenomena, but also obtained quantitative data in the form of sound intensity levels in decibels (dB). This data was then linked to the human hearing process, making learning more contextual, based on real data, and fostering students' scientific thinking and digital literacy skills.

From a content perspective, the validators stated that the content and presentation in the media were in line with the Learning Outcomes for Phase D in grade VIII of the Merdeka Curriculum, covering the relationship between physics concepts (sound waves) and biology (hearing mechanisms). The material was presented in a sequential, logical, and easy-to-understand manner, and was linked to everyday phenomena. The subject matter expert validator provided several suggestions for improvement, including enlarging the labels or descriptions on the model so that they are clearly legible, and adding visual indicators such as arrows to show the path of sound from the outside to the brain.

Meanwhile, from a media perspective, the validators assessed that the design and functionality of the tool were excellent, but recommended improving the material's resistance to water and weather so that the media would be more durable for long-term use. The tool could also be made more compact and portable, so that it would be easy for teachers to store and carry. In addition, further development can be carried out by integrating additional digital technologies, such as Augmented Reality (AR) or web-based media, to make the presentation of concepts more interactive and interesting. Validators also recommend that the media be used in interactive learning in a quiet room, with teacher assistance so that students do not just play with the tools, but truly understand the scientific concepts behind the experiments.

The development of the Biosonic Ear Model media is the answer to the need for interdisciplinary and experiential science learning because it combines the concepts of physics (sound waves, sound intensity) with biology (human hearing mechanisms) in one concrete tool. This media not only facilitates visual and practical understanding through physical models, but also utilizes the Sound Meter measurement application on mobile devices as a tool for measuring sound intensity from the tested source. Thus, students can take real (quantitative) measurements and relate them directly to the phenomena of the auditory system, enhancing the connection between student activities, empirical data, and the scientific concepts being studied. This is highly relevant to the finding that technology-based and interactive learning media have been proven to improve students' understanding of science (Muhtar, Nugraha, & Giyartini, 2020). This integration strengthens students' connections between theory and practice and directly addresses the low level of conceptual mastery in vibration and wave topics reported by Christiani, Munzil, and Yulianti (2021). Therefore, the developed media not only validates well in expert evaluation but also demonstrates strong pedagogical relevance to current educational challenges in the Education 5.0 era.

Based on the validation conducted by media and material experts, this media is considered to be of high quality in terms of content, design, and functionality. Aspects such as material accuracy, concept integration, practicality of use, and media appeal have been fulfilled, making this media suitable for testing in a real learning context with minor revisions. Suggestions such as strengthening the material to withstand classroom conditions, clarifying the anatomical labels of the ear, and utilizing a space conducive to sound measurement do not detract from the essence of the media. Thus, the Biosonic Ear Model can be used as an integrated science learning support media, connecting physics and biology concepts,

supported by real measurement technology, and aimed at improving the effectiveness and efficiency of science learning. Therefore, the Biosonic Ear Model has not only met the validation criteria but also demonstrated pedagogical potential to improve students' conceptual mastery through hands-on and technology-based learning.

CONCLUSION

Based on the results of research and validation, the Biosonic Ear Model learning media is declared suitable for use in integrated science learning with an average suitability score of 4.30, which is classified as very good. This media successfully integrates the physics concept of sound waves and the biology concept of the human auditory system into a single interactive and contextual three-dimensional model. Its main innovation lies in the use of the Sound Meter application on smartphones, which allows students to measure sound intensity directly, so that they not only understand the theory but also gain learning experiences based on experiments and real data. The integration of visual, practical, and digital aspects makes learning more meaningful and fosters scientific thinking and technological literacy in students. Thus, the development of the Biosonic Ear Model contributes significantly to strengthening the implementation of integrated science learning oriented towards sustainable education, as it helps students understand the interrelationships between scientific concepts holistically, encourages active participation, and supports the formation of scientific and ecological awareness in line with the demands of 21st-century learning. Future research is suggested to conduct classroom implementation and measure the media's effectiveness in improving students' conceptual understanding and scientific reasoning.

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