Development Of Visual-Tactile Media to Enhance Visually Impaired Students' Understanding of Light Concepts in Inclusive Classrooms

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Article History

Submitted: June 02, 2026
Accepted: July 11, 2026
Published: July 31, 2026

DOI:
https://doi.org/10.30822/magneton.v4i2.5501

ABSTRACT

Science instruction on the topic of light in inclusive classrooms still faces challenges, particularly for visually impaired students who struggle to understand concepts presented through visual representations. The limited availability of accessible instructional materials has resulted in suboptimal conceptual understanding among students. This study aims to develop valid, practical, and effective visual-tactile-based inclusive instructional materials to enhance visually impaired students' understanding of light concepts. This study employed the Research and Development (R&D) method using the ADDIE model, which includes the stages of analysis, design, development, implementation, and evaluation. The study subjects consisted of 33 eighth-grade students at SMPN 2 Watumalang, comprising 32 sighted students and 1 visually impaired student. Data collection was conducted through observation, interviews, expert validation sheets, student response questionnaires, as well as pretest and posttest assessments. The data were analyzed using the feasibility percentage, the Shapiro-Wilk test, the Wilcoxon Signed-Rank Test, and the N-Gain. The results showed that the developed media achieved a validity percentage of 95.83% from media experts, 93.75% from content experts, and 93.75% from practitioner experts, all falling into the "highly valid" category. The student response questionnaire yielded a percentage of 84.50%, classified as "highly practical." The results of the Wilcoxon test showed an Asymp. Sig. (2-tailed) value of 0.000 (<0.05), while the mean N-Gain value was 0.5917, categorized as moderate. Based on these results, the visual-tactile-based inclusive learning media was deemed valid, practical, and effective in improving students' understanding of light concepts in inclusive classrooms.

Keywords: Visual-Tactile Media; Inclusive Education; Visually Impaired Students; Conceptual Understanding; Light.

INTRODUCTION

Science education in the classroom still faces various challenges, particularly with abstract topics such as light. Most concepts related to light are presented through visual representations, such as images, diagrams, and experimental demonstrations, making them difficult for visually impaired students to access. This situation causes students with visual impairments to struggle in fully understanding concepts such as the direction of light propagation, reflection, refraction, and shadow formation (Castaneda et al., 2025) The administration of education in Indonesia is regulated by Law No. 20 of 2003 on the National Education System, which affirms that education

Volume 4, Nomor 2, July 2026
e-ISSN: 2985-5764

aims to develop students' potential so that they become individuals who are faithful, devout, knowledgeable, and responsible toward society and their environment (Republik Indonesia, 2003). With the evolution of the times and the digital era, particularly within the education system, the government continues to implement various reforms intended to address the current needs of society (Ministry of Education, Culture, Research, and Technology, 2024). However, the reality on the ground still reveals disparities in educational quality across regions, institutions, and student groups, including students with special needs, who often do not receive equitable educational services (Firdausyi, 2024).

In line with the policies of the Ministry of Education, Culture, Research, and Technology, deep learning is aimed at creating meaningful, reflective, and learner-centered learning experiences through active engagement in knowledge construction (Ministry of Education, Culture, Research, and Technology, 2024). This approach positions students as active agents who are expected to construct knowledge through exploration, problem-solving, and contextual learning experiences (Darling-Hammond et al., 2020). Deep learning also promotes high-level cognitive engagement so that students not only memorize information but are also able to understand, analyze, and apply concepts in real-world situations (Ministry of Education, Culture, Research, and Technology, 2024).

One of the key principles in implementing a deep learning-based curriculum is differentiated instruction that is, learning that adapts strategies, methods, and instructional media to students' diverse learning needs (Ministry of Education, Culture, Research, and Technology, 2024). In inclusive classrooms, the implementation of differentiated instruction is crucial because students have different characteristics, abilities, and learning needs, including both typically developing students and students with visual impairments. Therefore, learning materials must be designed to present concepts through representations that are accessible to all students. The visual-tactile learning materials developed in this study support differentiated instruction by providing concept representations that are accessible both visually and tactilely. Students in the general education population receive information through visual illustrations and the use of contrasting colors, while students with visual impairments explore the same concepts through raised lines, variations in texture, and tactile activities. Thus, all students learn the same material through representations tailored to their learning characteristics, thereby gaining equal opportunities to build conceptual understanding.

Inclusive education is a key concept that can be applied in Indonesia's education system, where it is defined as an educational approach that provides opportunities for all students including those with special needs to learn together in a regular school environment (Nahampun et al., 2025). Inclusive education aims to eliminate various learning barriers so that students with special needs can fully participate in learning activities alongside their peers. Various recent studies indicate that the successful implementation of inclusive education depends not only on the policies in place but also on the availability of learning strategies and resources capable of optimally accommodating the learning needs of students with special needs (Diasse & Kawai, 2024).

The success of inclusive education is also influenced by a school's ability to provide an accessible learning environment and learning resources capable of accommodating the needs of students with diverse characteristics. The provision of inclusive learning materials is a key factor in enhancing the participation and learning outcomes of students with special needs (Florian & Beaton, 2018). This situation was also observed at SMPN 2 Watumalang, a school that implements inclusive education. Based on initial observations and interviews with the science teacher, the eighth-grade class consists of 32 regular students and 1 visually impaired student who participate in learning together in the same classroom. During these joint learning sessions in the same classroom. During instruction, the teacher has made efforts to provide support to all students; however, the instructional materials used are still dominated by textbooks, images, and visual explanations, making them not yet fully accessible to the visually impaired student.

The implementation of inclusive education was strengthened by the issuance of the Minister of National Education Regulation (Permendiknas) No. 70 of 2009 on Inclusive Education, which provides students with special needs the opportunity to receive equitable educational services within the school environment (Ministry of National Education of the Republic of Indonesia, 2009). However, the implementation of inclusive education in regular schools still faces various challenges. Several previous studies have shown that inclusive schools often face limitations in providing adaptive learning resources and materials for students with special needs. In addition, teachers also often find it difficult to design learning strategies that can be followed by all students with different characteristics. This indicates that there remains a gap between inclusive education policies and actual teaching practices in schools (Suprihatiningrum, 2021). This situation has also been observed in various countries that have adopted inclusive education, particularly regarding the provision of accessible learning materials for students with visual impairments (Hayes & Proulx, 2024).

This issue becomes even more complex in the teaching of Natural Sciences (IPA). This subject emphasizes conceptual understanding through the scientific process, which involves observation, experimentation, and drawing conclusions about natural phenomena (Susanto, 2019). In science education, visual aids such as images, diagrams, graphs, and experimental demonstrations are frequently used to help students understand abstract concepts (Hayes & Proulx, 2024). This instructional approach is highly effective for students with normal vision; however, it can pose a barrier for students with visual impairments, such as the blind.

Students with visual impairments often struggle to understand the illustrations, diagrams, and images used in science education. This occurs because much of the information in science education is presented in visual formats that are inaccessible to students who are blind (Castaneda et al., 2025). Limited access to these visual representations impacts students' conceptual understanding, particularly for topics with highly visual characteristics, such as light. The topic of light encompasses concepts such as the direction of light propagation, reflection, refraction, shadow formation, and the properties of light which are typically studied through the observation of visual phenomena and experimental demonstrations. In teaching practice, teachers often use images, diagrams, and demonstrations to explain these concepts, so visually impaired students have difficulty understanding the material because they cannot directly observe light phenomena. Therefore, students with visual impairments require alternative representations that can be accessed through senses other than sight in order to develop a deeper conceptual understanding (Castaneda et al., 2025).

These findings align with the results of preliminary observations and interviews at SMPN 2 Watumalang. Teachers reported that visually impaired students struggle to understand the concepts of the direction of light propagation, reflection, refraction, and shadow formation because instruction is still dominated by the use of images in textbooks and visual demonstrations. During lessons, visually impaired students receive only verbal explanations without the support of tactile media; consequently, their ability to understand the relationships between concepts and light phenomena has not been optimized. This situation highlights the need for learning media capable of representing light concepts in an accessible manner through a combination of visual and tactile elements, so that they can be used by both typically developing students and visually impaired students in inclusive classrooms.

Consequently, limited access to visual media can affect students' conceptual understanding of science curriculum content. One area of science education that is highly visual in nature is the topic of light. This topic covers concepts such as the reflection of light, the refraction of light, the formation of shadows, and the properties of light which are typically studied through direct observation of visual phenomena. In practice, teachers often use images or experimental demonstrations to explain these concepts. For visually impaired students, these concepts are difficult to grasp because they cannot directly observe light phenomena. Students with visual impairments also require alternative representations accessible through senses other than sight to develop a deeper conceptual understanding in science learning (Castaneda et al., 2025).

Tactile graphics are raised graphical representations that allow students with visual impairments to access graphical information that was previously available only in visual form. Through tactile elements, such as raised lines, textures, and patterns, students who are blind can understand the shape, direction, relationships between components, and characteristics of an object more concretely. Research shows that the use of tactile graphics can improve visually impaired students' access to graphical information and support their understanding of scientific concepts through independent exploration using the sense of touch (Hahn et al., 2019).

Unlike tactile graphics, which focus on raised graphic representations, haptic media utilize haptic feedback technology to provide an interactive experience through digital devices. Visual-tactile media, on the other hand, integrate visual representations and tactile elements into a single learning medium so that it can be used simultaneously by both sighted and visually impaired students. The integration of these two representations allows all students to learn the same concepts by accessing information in ways that align with their individual learning styles. Furthermore, the use of tactile-based media in STEM education has been shown to help visually impaired students understand abstract concepts through hands-on learning experiences that involve exploring and touching learning objects (Akarsu et al., 2021).

Based on previous research, the use of adaptive tactile-based media has been shown to make a significant contribution to supporting science learning in inclusive schools. Tactile media allows students with visual impairments to gain concrete learning experiences through the manipulation of tactile objects, thereby helping them understand abstract scientific concepts in a more meaningful way. Combining visual and tactile elements in a single medium not only provides a more comprehensive learning approach but also aligns with the principles of inclusive education, which prioritize equal access for every student. A multisensory approach that combines visual and tactile elements can enhance the effectiveness of learning for both visually impaired and typically developing students because it engages more than one sense in the learning process (Chang et al., 2022). The support from these theories and research findings underscores the urgency of developing visual-tactile-based inclusive learning materials capable of bridging the gap between students' needs and the availability of accessible learning materials.

One approach that can be developed is the use of inclusive visual-tactile learning media that is, media that combines visual and tactile aspects. These materials enable students both typically developing and those with special needs to learn abstract concepts through the simultaneous use of touch. Multisensory-based materials such as visual-tactile resources can enhance concept retention and understanding for students, particularly those with different learning styles (Komalasari et al., 2019). These findings are supported by recent research showing that the integration of various sensory modalities such as visual, tactile, audio, and haptic technologies can improve learning accessibility and help students with visual impairments build a better conceptual understanding through multisensory learning experiences (Chit et al., 2024). The development of learning materials that integrate various modalities and technological support is one of the key directions in modern inclusive education. The use of technology designed to be accessible can increase participation, engagement, and learning opportunities for students with visual impairments in various learning contexts (Hamash et al., 2024).

Visual-tactile learning materials on the topic of light, specifically designed for inclusive classrooms, were developed in the form of a tactile relief model. This model features light path indicators, different textures to demonstrate reflection and refraction, and high-contrast visual elements, making it suitable for use by both typically developing students and students with visual impairments. The developed materials were also designed using a multisensory approach so that students can understand the concept of light through visual observation, tactile exploration, and direct discussion. Additionally, these materials can be used in differentiated instruction because they allow students to learn according to their individual needs and learning styles.

This study offers a novel approach through the development of inclusive, visual-tactile learning materials designed to support science learning on the topic of light for visually impaired students in inclusive schools. Unlike previous studies, which generally developed tactile or multisensory materials, the materials developed in this study integrate high-contrast visual elements with tactile features such as raised lines, varied textures, light path indicators, and shadow formation. These elements can be explored through both visual and tactile representations, allowing visually impaired students to engage in a single multisensory learning process and differentiated instruction tailored to their individual learning needs. Therefore, this study aims to develop and validate a valid, practical, and effective visual-tactile-based learning

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e-ISSN: 2985-5764

medium to improve the understanding of light concepts among eighth-grade students at SMPN 2 Watumalang, Wonosobo Regency.

METHOD

This study is a research and development (R&D) project aimed at producing inclusive visual-tactile-based learning media to improve the understanding of light concepts among visually impaired students in inclusive classrooms. Product development followed the ADDIE model, which consists of five stages: analysis, design, development, implementation, and evaluation (Branch, 2009). This model was chosen because it provides a systematic procedure for developing, testing, and evaluating learning products.

The study was conducted at SMPN 2 Watumalang, Wonosobo Regency. The research subjects consisted of all eighth-grade students in an inclusive classroom, totaling 33 students, comprising 32 sighted students and 1 visually impaired student. The sampling technique used was total sampling, as the entire population was included as the research sample. An analysis of the media's effectiveness was conducted on all students in the inclusive classroom to determine improvements in conceptual understanding following the use of the learning media. Given that the visually impaired student was the only subject, the visually impaired student's learning outcomes were not analyzed statistically but were presented descriptively through a comparison of pretest and posttest results, supported by observations made during the learning process. The presentation of this data is intended to provide an overview of the use of visual-tactile media in enhancing the conceptual understanding of a visually impaired student within the context of an inclusive classroom.

a. Analysis Stage

The analysis phase aims to identify the learning needs that underlie the development of the media. The analysis was conducted through observations and interviews with the science teacher to obtain information regarding learning conditions, student characteristics, and challenges faced during instruction. In addition, an analysis was conducted of the curriculum, learning outcomes, learning objectives, and the characteristics of the concept of light which is abstract in nature and requires concrete representation. The analysis also focused on the needs of both visually impaired and regular students to ensure that the developed media can be used inclusively.

b. Design Phase

The design phase was carried out to develop the media design based on the results of the needs analysis. In this phase, the visual and tactile design of the media, the structure of the content, and supporting narratives accessible to visually impaired students were developed. The media was designed to measure 40 cm × 40 cm, using styrofoam as the base material. Tactile elements are made using paper to form light-paths, raised lines, and patterns representing the concepts of reflection, refraction, and shadow formation, while EVA foam is used to create textural variations in specific areas, making it easier for students to distinguish each component of the media through touch. The media is also equipped with Braille labels to provide information, making it accessible to visually impaired students, while the use of contrasting colors in the visual sections makes it easier for sighted students to observe each component of the media.

In this activity, visually impaired students explore media through tactile activities by following raised paths and systematically distinguishing variations in texture to understand the direction of light propagation, the relationships between components, and the processes of reflection, refraction, and shadow formation. In addition, at this stage, research instruments were developed, including validation sheets for media experts, subject matter experts, and practitioners, a student practicality questionnaire, as well as pretest and posttest instruments. The outcomes of this stage were a blueprint and an initial prototype of the visual-tactile learning media, which were further developed in the next stage.

c. Development Stage

The development phase involves turning the design into an inclusive, visual-tactile-based instructional media product. The media is developed using visual and tactile components designed to help students understand the concept of light through multisensory learning experiences. The

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e-ISSN: 2985-5764

developed product is then validated by media experts, content experts, and practitioner experts to assess its suitability. Validation by media experts focuses on the media's design, visual-tactile components, ease of use, and practicality. Validation by subject matter experts covered the appropriateness of the content, conceptual accuracy, presentation of the material, and alignment with inclusive learning. Meanwhile, validation by practitioners was conducted to assess the media's alignment with learning needs, ease of use, usefulness, and practicality. The validation results were used as the basis for revising and refining the product before its implementation.

d. Implementation Phase

The implementation stage was carried out through a pilot test of the media in science lessons on the topic of light in an inclusive classroom at SMPN 2 Watumalang, Wonosobo. Before the lessons began, students took a pretest to assess their initial understanding of light concepts. Subsequently, instruction was conducted using the newly developed visual-tactile inclusive learning media. After the lesson concluded, students took a posttest to measure improvements in their conceptual understanding, as well as a feedback questionnaire to assess the practicality of the media. The results from this stage were used to determine the effectiveness and practicality of the learning media.

e. Evaluation Stage

The evaluation stage is the final stage conducted at each phase of development to ensure the product aligns with the established objectives. Evaluation is based on expert validation results, user feedback, and student learning outcomes. The findings are used as the basis for refining the product to produce learning media that is valid, practical, and effective for use in science instruction in inclusive classrooms.

Data collection techniques are employed to obtain the necessary information at each stage of development. In this stage, research data is collected using both test and non-test techniques. Non-test techniques include validation forms completed by media experts, subject matter experts, and practitioners, as well as student response questionnaires. Validation forms were used to assess the media's suitability, practicality (based on ease of use), appeal, clarity of presentation, and educational benefits. Test-based methods employed pretest and posttest instruments to measure students' understanding of light concepts before and after using the instructional media.

The test-based techniques use pretest and posttest instruments consisting of 25 multiple-choice questions designed based on indicators of understanding of light concepts, including the ability to identify, classify, explain, and apply light concepts. The instruments were developed in accordance with the learning objectives and underwent expert validation to ensure the appropriateness of content, construction, and language. Specifically for visually impaired students, the test administration was adapted so that the questions were read aloud by the researcher, allowing students to understand each item and provide answers according to their abilities. This adaptation was implemented to ensure that the measurement of conceptual understanding was not influenced by limited access to visual media.

The data obtained were then analyzed to determine the validity, practicality, and effectiveness of the visual-tactile-based inclusive learning media. The data from the validation by media experts, subject matter experts, and practitioners, as well as the student response questionnaires, were analyzed using quantitative descriptive methods based on the percentage of acceptability using the following formula:

$$P_k = \frac{S}{N} \times 100\%$$

Notes:

P_k : Feasibility Percentage
S : Total score obtained
N : Maximum possible score

The percentage results were used to determine the level of validity and practicality of the instructional media. Subsequently, the effectiveness of the media was analyzed based on the pretest and posttest results. The improvement in understanding of light concepts was calculated using the N-Gain test (Sundayana, 2019). Before hypothesis testing, the data were tested for normality using the Shapiro-Wilk test because the sample size was less than 50 (Ahadi & Zain, 2023). If the data were not normally distributed, hypothesis testing was conducted using the Wilcoxon Signed-Rank Test to determine differences between pretest and posttest results in the inclusive classroom. Given that the research subject consisted of only one visually impaired student, the results of the statistical analysis were used to describe the effectiveness of the instructional media in the inclusive classroom as a whole, while the visually impaired student's learning outcomes were presented and interpreted descriptively through a comparison of pretest and posttest scores as well as observation results during instruction.

The test results indicated that the data were not normally distributed ($p < 0.05$); therefore, the analysis proceeded using the nonparametric Wilcoxon Signed-Rank Test to determine differences in students' conceptual understanding before and after the use of instructional media. The test was conducted at a significance level of 0.05. The learning media was deemed effective if it demonstrated an improvement in learning outcomes based on the N-Gain category and there was a significant difference between the pretest and posttest scores.

RESULTS AND DISCUSSION

The development of visual-tactile-based inclusive learning media was carried out using the ADDIE model, which consists of the analysis, design, development, implementation, and evaluation stages. During the analysis phase, it was found that the topic of light remains difficult for students to understand due to the many abstract concepts involved. This situation also poses a unique challenge for visually impaired students, who face limitations in accessing visual information. Therefore, instructional media capable of presenting the concept of light through a combination of visual and tactile elements is needed so that it can be used by both regular students and visually impaired students in an inclusive classroom.

During the design phase, a learning medium was developed that incorporates visual and tactile components to represent the concepts of light more concretely. The medium was designed with accessibility for visually impaired students in mind through the use of different textures, raised lines, symbols, and tactile labels.

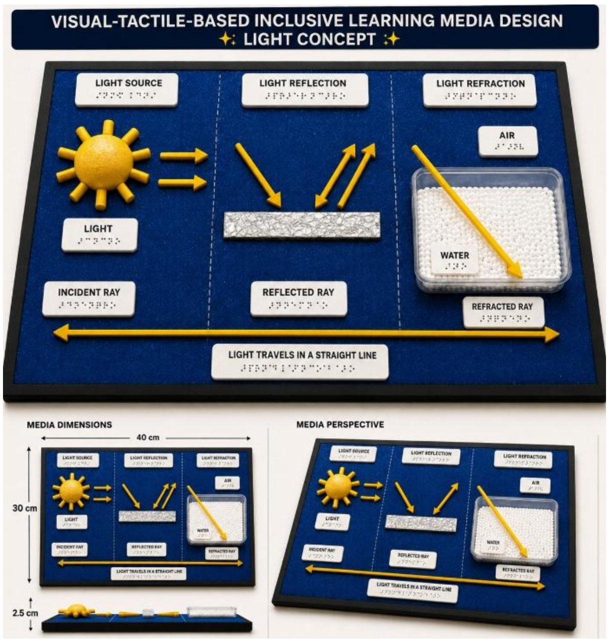

Figure 1. Design of an Inclusive Visual-Tactile-Based Learning Medium on the Topic of Light, Showing Visual and Directional Components

Based on the design that has been developed, the next stage is the development stage, which involves turning the design into an instructional media product. The resulting product consists of visual and tactile components that can be used to explain the concepts of light traveling in a

Volume 4, Nomor 2, July 2026
e-ISSN: 2985-5764

straight line, light reflection, and light refraction. The media is designed so that students can observe, touch, and explore the concepts directly, thereby making learning more meaningful.

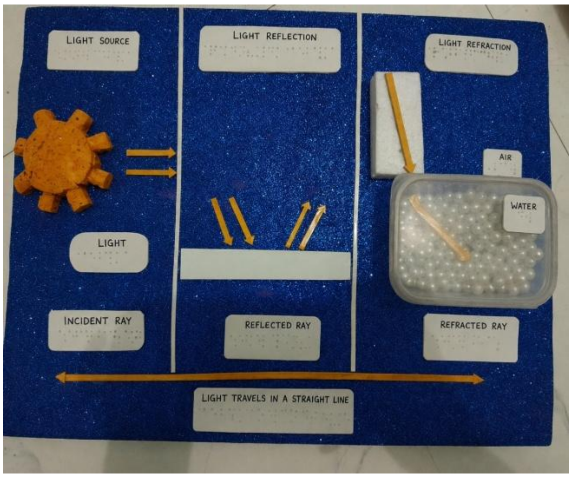

Figure 2. Final Product of Visual-Tactile-Based Inclusive Learning Media

The developed product was then validated by media experts, subject matter experts, and practitioners before being implemented in science instruction in inclusive classrooms. The visual-tactile-based inclusive learning media that were developed underwent a validation process by media experts, subject matter experts, and practitioners. Validation was conducted to assess the media's suitability in terms of design, content appropriateness, and its application in inclusive learning. The results of the learning media validation are presented in the following table1.

Table 1. Results of Learning Media Validation

Validator	Average Score	Percentage	Category
Media Expert	3.84	95.83%	Highly Valid
Content Expert	3.75	93.75%	Highly Valid
Practitioner Expert	3.75	93.75%	Highly Valid

Based on the validation results by the validators, the developed learning media received a "highly valid" rating from media experts with a percentage of 95.83%, a rating of 93.75% from content experts, and a rating of 93.75% from practitioner experts. The results of this validation indicate that the media meets the validity criteria in terms of design, content appropriateness, and implementation in learning, making it suitable for use in the pilot testing phase.

Nevertheless, the media still underwent refinements based on the validation results. The revisions focused on improving the direction of light reflection to align with the concept of the law of reflection and make it easier for students to understand. These refinements were made to enhance the accuracy of the concept's representation in the media, ensuring that the implemented product aligns with scientific concepts.

The practicality of the learning media was analyzed based on the results of a student response questionnaire after using the visual-tactile-based inclusive learning media. A practicality assessment was conducted to determine the ease of use and usefulness of the media in learning. The results of the media practicality analysis are presented in the following table 2.

Table 2. Results of the Practicality of Learning Media

Average Score	Percentage	Category
3.38	84.50%	Very Practical

Based on the analysis results, the developed instructional media received a "highly practical" rating. These results indicate that the media is easy for students to use, helps them understand the concept of light, and can support instruction in inclusive classrooms. Therefore, the developed instructional media has a high level of practicality and is suitable for use in the learning process.

The effectiveness of the learning media was analyzed based on students' pretest and posttest results. Before testing the hypotheses, the data was first tested for normality using the Shapiro-Wilk test to determine the data distribution. The results of the normality test are presented in the following table:

Table 3. Normality Test Results

Data	Sig.	Notes
Pretest	0.003	Not Normal
Posttest	0.001	Not Normal

Based on the results of the normality test, the significance values for the pretest and posttest data were each less than 0.05, indicating that the data are not normally distributed. Therefore, the analysis continued using the nonparametric Wilcoxon Signed-Rank Test. Before testing the hypotheses, the descriptive statistics for the pretest and posttest scores are presented in the following table:

Table 4. Descriptive Statistics of Pretest and Posttest Scores

Data	N	N	Mean	SD	Median	Minimum	Maximum
Pretest	33	78.36	3.92	80	80	72	84
Posttest	33	90.91	3.91	92	92	84	96

Based on Table 4, there was an increase in learning outcomes following the use of the developed instructional media. The mean score increased from 78.36 on the pretest to 90.91 on the posttest. In addition, the median score increased from 80 to 92, the minimum score increased from 72 to 84, and the maximum score increased from 84 to 96. These results indicate an improvement in the understanding of light concepts following the use of the instructional media.

Table 5. Results of the Nonparametric Test

Z	Asymp. Sig. (2-tailed)	Decision
-5.158	0.000	There is a significant difference

According to, the results of the Wilcoxon Signed-Rank Test yielded an Asymp. Sig. (2-tailed) value of 0.000 (<0.05). These results indicate that there is a significant difference between pretest and posttest scores following the use of visual-tactile-based inclusive learning media. In addition, all students experienced an improvement in learning outcomes, as indicated by positive ranks for 33 students, with no negative ranks or ties.

These findings indicate that the learning media had a positive effect on improving the understanding of light concepts in an inclusive classroom. Individually, the visually impaired student also showed an improvement in scores from 72 on the pretest to 88 on the posttest, demonstrating that the developed media effectively supported the understanding of light concepts through accessible visual and tactile representations.

Furthermore, to determine the level of improvement in students' conceptual understanding, an analysis was conducted using the N-Gain test. The results of the N-Gain test analysis are presented in the following table:

Table 5. N-Gain Test Results

N-Gain	Category
0.5917	Moderate

Based on the results of the N-Gain test, the average N-Gain value was 0.5917, which falls into the "moderate" category. These results indicate that visual-tactile-based inclusive learning media can improve students' understanding of the concept of light at a moderate level and are considered quite effective for use in science instruction in inclusive classrooms.

The development of visual-tactile-based inclusive learning materials has been shown to make a positive contribution to the science learning process when teaching the topic of light in inclusive classrooms. These materials create a more engaging, interactive, and meaningful

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e-ISSN: 2985-5764

learning environment, encouraging students to participate more actively in the learning process. Research results show that the developed materials are effective in improving conceptual understanding of light among both regular students and students with visual impairments. This success is attributed to the integration of visual and tactile components, which allows students to grasp the concept through more than one sensory modality.

For students with typical vision, the concept of light is understood through visual observation of illustrations and the direction of light propagation, whereas for students with visual impairments, the same concept is learned through exploration of textures, raised surfaces, light propagation paths, and Braille labels. Therefore, the teaching aid provides conceptual representations tailored to each student's learning characteristics, thereby supporting differentiated instruction in inclusive classrooms.

These findings align with multisensory learning theory, which explains that engaging more than one sense in the learning process can strengthen concept formation, improve information retention, and facilitate understanding of abstract material (Komalasari et al., 2019). In the topic of light, which is generally presented through visual illustrations, the use of tactile components provides an alternative nonvisual representation so that visually impaired students can still build understanding through tactile activities.

The research findings are also consistent with constructivist theory, which states that knowledge is actively constructed through learning experiences and direct interaction with learning objects (Piaget, 1950). Visual-tactile media provide students with the opportunity to explore the concept of light independently through observing, touching, and discussing their observations. Such concrete learning experiences help students build a more meaningful conceptual understanding compared to simply receiving verbal explanations.

The findings of this study are also supported by previous research showing that the use of tactile-based media and multisensory approaches can improve the accessibility of science learning for students with visual impairments and help them understand abstract concepts through hands-on learning experiences (Akarsu et al., 2021; Chang et al., 2022; Chit et al., 2024). Thus, the visual-tactile-based inclusive learning media developed is not only feasible and practical to use but also serves as an alternative science learning medium capable of supporting inclusive learning by providing accessible conceptual representations for both regular students and students with visual impairments.

CONCLUSION

This study successfully developed visual-tactile-based inclusive learning media on the topic of light, designed to support learning in inclusive classrooms, particularly for visually impaired students. The developed media received a "highly valid" validity rating, with a percentage of 95.83% from media experts, 93.75% from content experts, and 93.755 from practitioner experts. The results of the practicality test showed that the media received positive responses from students, indicating that it is easy to use in the learning process. The effectiveness of the media was demonstrated by the results of the Wilcoxon Signed-Rank Test, which yielded an Asymp. Sig. (2-tailed) value of 0.000 (< 0.05), indicating a significant difference between pretest and posttest scores. Furthermore, the average N-Gain value of 0.5917 falls into the "moderate" category, indicating that the media is capable of improving students' conceptual understanding of light in an inclusive classroom. This study has limitations because it involved only one visually impaired student; therefore, the results regarding the effectiveness of the media for visually impaired students cannot yet be widely generalized. Consequently, future research is recommended to involve a larger number of visually impaired students and to implement the media at various grade levels and within different inclusive school contexts to obtain a more comprehensive picture of its effectiveness.

Volume 4, Nomor 2, July 2026
e-ISSN: 2985-5764

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