

MATILDES: Development of an Inclusive Tactile Media for Teaching Archimedes' Principle to Visually Impaired Students

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Abstract

This research aims to develop Archimedes' Law Tactile Media (MATILDES) as an inclusive physics learning medium for blind students in Special Senior High Schools (SMALB). The concept of Archimedes' Law, which explains the conditions of floating, hovering, and sinking, is difficult for blind students to understand because physics lessons are generally presented through visual representations. This research used a Research and Development (R&D) method with the Successive Approximation Model (SAM) consisting of a preparation phase, an iterative design phase, and an iterative development phase. The developed media integrates simple experiments on floating, hovering, and sinking conditions with tactile representations and Indonesian Braille labels (BBIU) to support a multisensory learning experience. The development results show that MATILDES was successfully realized in the form of tactile learning media consisting of a fluid experiment kit, a three-panel tactile board, a Braille-based user guide board, and a mathematical symbol board for density relationships. MATILDES is designed to support more accessible physics learning and help blind students build a more concrete and meaningful understanding of the concept of Archimedes' Law, while strengthening their tactile and kinesthetic sensory skills through hands-on exploration. Expert validation involving physics-education and inclusive-education validators produced feasibility scores of 100% and 93.75% respectively, while a one-on-one trial with five visually impaired students yielded a mean score of 99%, covering media accessibility, safety, and material suitability. Both the expert-validation scores fall within the "Very Feasible" category, and the user-trial score falls within the "Very Good" category, indicating that MATILDES is ready for use in inclusive physics classrooms. The study concludes that combining direct fluid

experimentation with tactile and Braille representation offers a practical pathway for teaching abstract physics concepts to learners who cannot rely on visual demonstration.

Keywords: *tactile media; SAM model; Archimedes' principle; inclusive education; blind students*

1. INTRODUCTION

Physics education for visually impaired students requires learning media that replaces visual information with tactile and auditory stimulation. Without accessible media, visually impaired students are excluded from the dimension of the physics learning experience that is central to conceptual understanding (Bano et al., 2023). This gap is particularly evident in concepts that rely heavily on observation, such as Archimedes' Principle, which describes the buoyancy force acting on objects submerged in fluids and underlies the phenomena of floating, neutral buoyancy, and sinking (Neri et al., 2024). Developing accessible media for this concept is particularly important because Archimedes' Principle is a mandatory topic in the Grade XI Physics Learning Outcomes of the Kurikulum Merdeka for SMA/SMALB (Badan Standar, Kurikulum, dan Asesmen Pendidikan, 2022), and preliminary observations at Special Schools in South Tangerang identified it as the physics topic with the widest gap in tactile-media availability compared with other topics that can still be partly explained through touching everyday objects.

Archimedes' principle states that the buoyancy force (F) acting on an object submerged in fluid is equal to the weight of the fluid displaced by the object. This relationship can be expressed as:

$$F = \rho_f \times g \times V \quad (1)$$

where F is the buoyancy force (N), ρ_f is the density of the fluid (kg/m^3), g is the acceleration of gravity (m/s^2), and V is the volume of fluid displaced by the object (m^3). Therefore, the condition of an object in a fluid is determined by the relationship between the density of the object (ρ_b) and the density of the fluid (ρ_f): if $\rho_b < \rho_f$ the object floats; if $\rho_b = \rho_f$ the object reaches neutral buoyancy; and if $\rho_b > \rho_f$ the object sinks.

Field observations at Special Schools in South Tangerang revealed that physics teaching for blind students at the SMALB level remains predominantly verbal, without tactile media made specifically for fluid mechanics. Teachers reported difficulty conveying abstract relationships of the Archimedes Principle without visual aids, consistent with the barriers to

access documented by Johansson et al. (2022) and Ainscow (2022), who identified the lack of adapted material as an important systemic barrier to inclusive education.

Research has consistently shown that tactile and multisensory learning approaches substantially improve conceptual comprehension among visually impaired students. Shams and Seitz (2023) show that multisensory learning leads to stronger memory encoding compared to unisensory instruction, while McLinden et al. (2024) affirm that tactile representations are most effective when reinforcing previous physical experiences. In the context of science learning, Tawfik et al. (2022) reported significant gains in conceptual understanding when tactile-based materials were used with visually impaired students. More recently, Chit et al. (2024) demonstrated that combining tactile, haptic, and auditory media within a multisensory learning framework increased usability and learning engagement among visually impaired learners, while Kirboyun Tipi et al. (2023) found that touch-based concept-teaching models enabled visually impaired students to learn independently and at their own pace. These findings are consistent with the systematic review by Fardan et al. (2023), which identified textured and object-based tactile stimuli as the most effective modality for supporting concept recognition in blind children.

Despite this evidence, tactile media designed specifically for the Archimedes Principle remains unavailable in Indonesia's special education environment. Therefore, this study developed MATILDES (Archimedes' Law Tactile Media), a two-stage tactile learning medium that combines direct fluid experimentation with raised tactile boards and Braille labels in the BBIU, designed to make the Archimedes Principles accessible and self-taught for visually impaired students at the SMALB level (Fitri et al., 2025).

2. RESEARCH METHODOLOGY

The study uses a Research and Development (R&D) approach using the Successive Approximation Model (SAM) (Iskandar et al., 2022), chosen for its iterative structure and user responsiveness that allows for continuous prototype refinement an important advantage when developing media for learners with specific sensory needs. The SAM model consists of three main phases as illustrated in Figure 1. In the Preparation Stage, needs analysis is carried out through semi-structured teacher interviews and direct classroom observation at Special Schools in South Tangerang, establishing student profiles and initial design specifications. In the Iterative Design Phase, the MATILDES prototype is designed as a two-stage learning

sequence and undergoes rapid prototyping with initial expert review. In the Iterative Development Phase, physical media is built, revised based on expert input, revised, and prepared for limited user testing as a final product.

Instrument validation was carried out through expert judgment involving three validators: two physics-education experts and one inclusive-education expert. Each validator rated the media using a structured questionnaire on a 1–4 rating scale covering aspects of physics-concept accuracy, multisensory-learning alignment, and suitability for the characteristics and needs of visually impaired learners. The scores obtained were summed and converted into a feasibility percentage using the formula: Percentage of Feasibility (%) = (score obtained / maximum score) × 100%, and interpreted according to four categories adapted from Akbar (2013): Very Feasible (85–100%), Feasible (70–85%), Fairly Feasible (55–70%), and Not Feasible (≤55%). Following expert validation, a one-on-one user trial was conducted with five visually impaired students at SKH Yarfin, South Tangerang, using the same feasibility-percentage procedure to assess media accessibility, safety, and material suitability.

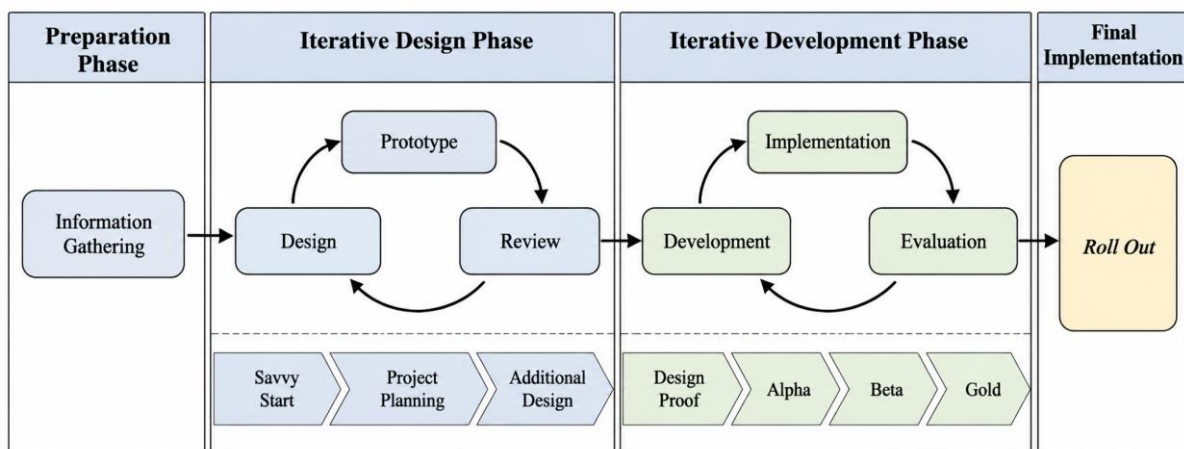


Figure 1. Successive Approximation Model (SAM) Development Phase

3. RESULTS AND DISCUSSION

Results

Expert Validation and User Testing Results

Expert validation showed that MATILDES obtained a mean score of 100% from the two physics-education validators and 93.75% from the inclusive-education validator, both falling

into the “Very Feasible” category. Physics-education validation indicated full alignment (100%) with Archimedes' Principle concepts, density-symbol accuracy, and multisensory-learning principles. Inclusive-education validation showed most indicators reaching 100%, while the totality-method and independent-learning-support indicators scored 75%, still within the Very Feasible range. Following revision based on validator feedback, a one-on-one user trial with five visually impaired students (three female, two male; aged 15–20) at SKH Yarfin, South Tangerang, produced a mean (score of 99%, categorized as “Very Good”), on the user-trial perception scale, distinct from the four-category expert-validation feasibility scale described in the Methods section, covering media accessibility (97.6%), safety (100%), and material suitability and learning independence (100%), confirming that MATILDES is highly feasible as an inclusive physics learning medium.

Characteristics of Developed MATILDES

MATILDES (Archimedes' Law Tactile Media) is a two-stage inclusive learning medium developed through the Successive Approximation Model, combining hands-on fluid experimentation with a tactile representation board to make Archimedes' Principle accessible to visually impaired students. Based on the results of the needs analysis at the SMALB special school, visually impaired students need learning media that can replace visual representation with learning experiences that can be accessed through the senses of touch and direct activities. Therefore, MATILDES was developed as an inclusive tactile and multisensory physics learning medium to help students understand the concepts of Archimedes' Law.

Developed Equipment Design

MATILDES is designed as a two-stage learning medium that integrates simple fluid experimentation and tactile representation. The media design utilizes laser-cut wooden boards equipped with embossed textures, density symbols, and BBIU Braille labels to support accessibility for visually impaired students. The design of the developed media is shown in Figure 2.



Figure 2. Complete Set of MATILDES Learning Media

MATILDES Media Development Results

The results of MATILDES development consist of five main components, namely fluid experiment kits, three-panel tactile boards, Braille-based user guide boards, object condition boards and density symbols, and media storage boxes.

a) Fluid Experiment Kits (containers and water)

The fluid experiment kit consists of one transparent container and three bottles with different densities. The first bottle is filled with gravel so that it has a density greater than water and indicates a submerged condition. The second bottle is designed to have a density close to the density of water so that it shows a floating condition. The third bottle has a smaller density than water so it indicates floating conditions. This component serves to provide direct experience to visually impaired students in observing the phenomenon of Archimedes' Law through touch activities and object manipulation.

b) Three-Panel Tactile Board

The characteristics of the three panels on the tactile board allow students to directly compare the three conditions of objects in fluids, namely floating, floating, and sinking. Representations presented side-by-side help students build a conceptual relationship between the position of the object and the ratio of the density of the object to the density of the fluid. Thus, tactile boards serve not only as physical representations, but also as a means of conceptual formation through tactile exploration experiences.

c) MATILDES Usage Guideboard

The use guide board is presented in BBIU Braille so that it can be read independently by visually impaired students. This guide contains steps to use media from conducting experiments to linking observations with representations on a touch board. The existence of

Braille-based guides allows blind students to access media use instructions without full dependence on teachers. This feature supports independent learning while strengthening the function of MATILDES as an accessible learning medium for students with visual impairments.

d) Object Condition Board with Density Symbol

The presentation of density symbols in the form of cautionary writing and Braille serves as a bridge between the concrete experiences students gain during the experiment and the symbolic representation of Archimedes' Law. The presence of these symbols helps students connect the phenomenon of floating, floating, and sinking with the underlying scientific concepts so that the process of conceptual abstraction can take place more gradually.

e) Media Storage Box

All MATILDES components are stored in a specially designed wooden box to maintain the safety of the media and facilitate storage and mobility. The storage box is also equipped with media identity and Braille writing so that it is easily recognized by users.



Figure 3. Fluid Experiment Kits (containers and water)



Figure 4. Three-Panel Tactile Board

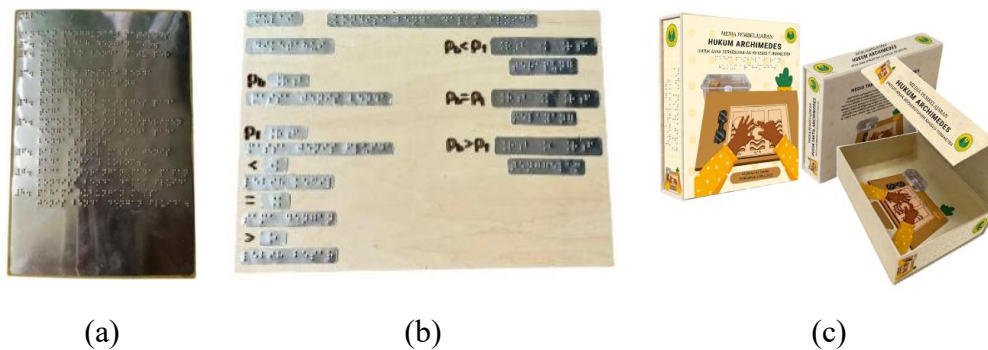


Figure 5. (a) MATILDES Usage Guideboard; (b) Object Condition Board with Density Symbol; (c) Media Storage Box

Discussion

Building on the expert validation and user testing results presented above, the following discussion examines how the characteristics of MATILDES align with scaffolding, inquiry-based, and multisensory learning principles. The development of MATILDES was focused on creating an inclusive learning environment that replaces visual information with tactile and kinesthetic learning experiences. The characteristics of the media, which integrate a simple fluid experiment with tactile representations, demonstrate alignment with scaffolding theory, which emphasizes the provision of structured support to help learners gradually develop conceptual understanding and achieve independent learning. In the implementation of MATILDES, students first engage in direct experimentation using a water container and objects with different densities to observe the phenomena of floating, neutral buoyancy, and sinking. After obtaining concrete experiences, students proceed to explore the tactile board containing representations of object positions in fluids, density symbols, and Indonesian Unified Braille (BBIU) labels. This learning sequence enables students to construct their understanding of Archimedes' Principle progressively, moving from concrete experiences to more abstract conceptual representations. This design principle is consistent with Raynal et al. (2024), who showed that combining tactile graphics with tangible, manipulable components improves the flexibility and usability of teaching materials for people with vision impairments. Johansson et al. (2022) reported that structured learning support allows students with disabilities to achieve greater learning independence. Furthermore, the Braille labels embedded in each component of MATILDES function as cognitive scaffolds that assist students in understanding the relationship between object density and fluid density

independently. This finding is consistent with Kurniawati and Yuwono (2024), who demonstrated that Braille-based learning media can significantly enhance accessibility and independent learning among visually impaired students.

In addition to supporting scaffolding, the characteristics of MATILDES are also consistent with the principles of inquiry-based learning. During the experimental stage, students are not merely passive recipients of information; instead, they actively participate in a simple investigative process by exploring the behavior of objects placed in water. Through activities such as inserting, holding, and examining the position of objects in the fluid, students are encouraged to connect their sensory experiences with the concepts of density and buoyant force. These activities reflect the essential characteristics of inquiry learning, which emphasize active student engagement in scientific investigation and knowledge construction. Bano et al. (2023) argued that direct involvement in exploratory activities enhances conceptual understanding because learners construct knowledge through personal experiences. This perspective is further supported by Phutane et al. (2022), who found that tactile media used in scientific investigations can help visually impaired students develop a deeper and more meaningful understanding of scientific concepts compared with purely verbal instruction.

Another prominent characteristic of MATILDES is its application of multisensory learning principles. The media were designed to optimize multiple sensory modalities within an integrated learning sequence. The fluid experiment activates kinesthetic experiences through direct manipulation of objects, while the tactile board engages the sense of touch through raised wave textures, embossed objects, density symbols, and Braille labels. The integration of these sensory experiences allows students to access and process information through multiple channels simultaneously. Shams and Seitz (2023) demonstrated that multisensory learning produces stronger and more durable memory traces than learning experiences that rely on a single sensory modality. This view is reinforced by McLinden et al. (2024), who identified multisensory approaches as one of the most effective strategies for supporting conceptual understanding among visually impaired learners, as they enhance accessibility and facilitate meaningful concept formation through multiple sensory pathways.

Overall, MATILDES functions not only as a tactile representation of Archimedes' Principle but also as a learning medium that integrates scaffolding, inquiry-based learning, and multisensory learning principles. The combination of these pedagogical approaches enables visually impaired students to engage in more active, independent, and meaningful

learning experiences while developing a deeper understanding of the concepts of floating, neutral buoyancy, and sinking.

4. CONCLUSIONS

MATILDES (Archimedes' Law Tactile Media) has been successfully developed as an inclusive physics learning medium for visually impaired students in Archimedes' Law material. This medium integrates simple fluid experimental activities, tactile representations, to help students understand the concepts of floating, floating, and sinking through a multisensory learning experience. The characteristics of MATILDES which are in line with the principles of scaffolding, inquiry learning, and multisensory learning show its potential as an alternative learning media that can help visually impaired students build a more independent and meaningful understanding of concepts.

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