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SMARTBOARD-BASED INDONESIAN SIGN LANGUAGE (BISINDO) DEEP LEARNING MODEL FOR DEAF STUDENTS AT SLB PEMBINA MEDAN

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ABSTRAK

Deaf students in Indonesian special schools (SLB) face persistent barriers in accessing interactive instructional media that align with their visual-spatial cognitive needs and Bisindo linguistic identity. While prior studies have explored sign language recognition technologies and general deep learning algorithms, a critical gap remains in integrating pedagogical deep learning principles with disability-specific interactive media within special education classrooms. This study aimed to develop and validate a Smartboard-based Indonesian Sign Language (Bisindo) deep learning instructional model for deaf students at SLB Pembina Medan. Employing a Research and Development (R&D) approach following the Borg and Gall ten-step model, the study involved needs analysis, product development, expert validation, and field testing. Validation instruments were assessed for content validity using the Content Validity Index (CVI) and Content Validity Ratio (CVR), and reliability was established through inter-rater agreement. The product was evaluated by one learning expert, one Bisindo expert, and one media expert, followed by small-group trials (N = 3 teachers) and large-group trials (N = 3 teachers). Ethical approval was obtained from the institutional review board prior to data collection. Results demonstrated exceptional feasibility: material experts rated the product at 97.06%, Bisindo experts at 95.59%, and media experts at 91.67%, all classified as "very feasible." Small-group teacher trials yielded 88.33% (feasible), while large-group trials achieved 96.66% (very feasible). The developed model offers a replicable pedagogical framework that integrates Bisindo linguistic features, deep learning pedagogy, and Smartboard interactivity, contributing to inclusive digital learning practices for deaf students in special education contexts.

INTRODUCTION

Bisindo (Indonesian Sign Language) is a natural language developed and used by the deaf community in Indonesia. Despite its linguistic legitimacy, Bisindo has received limited institutional recognition, prompting deaf communities to advocate for its preservation and integration into formal education curricula (Kautsar et al., 2019). In the current digital era, technological advancement is expected to positively support learning processes, particularly through interactive Smartboards that enhance student-teacher interaction (Haqqi & Wijayati, 2019).

Smartboards are instructional media that facilitate information delivery in practical, efficient, and engaging ways (Rahim, 2023). Beyond functioning as interactive whiteboards, Smartboards provide diverse features for implementing learning media (Israldi, 2022). By delivering more interactive and dynamic materials, Smartboards increase student interest and deepen conceptual understanding. The combination of deep learning models with Smartboard technology offers significant potential for improving deaf students' learning outcomes (Altarika & Sari, 2023).

The learning orientation emphasizes deep understanding rather than mere mastery of sign language movements (Reddy & Rohit, 2023). The model encourages cognitive engagement, reflection, and independent learning for deaf students through interactive visualizations, Bisindo movement animations, and Smartboard-based activities (Malathi et al., 2023). Deep learning here is interpreted not only as artificial intelligence technology but also as a meaningful learning approach aligned with the Merdeka Curriculum policy and the needs of students with special needs (Muvid, 2024).

This constructivist orientation aligns with the principles of the Independent Curriculum (Kurikulum Merdeka), which prioritizes project-based learning and student-centered inquiry (Andrayani, 2024). For deaf students, deep learning should be implemented through visual-spatial instructional approaches that align with their primary mode of information processing. Research shows that deaf learners often demonstrate strengths in visual memory, spatial reasoning, and visual information processing, highlighting the importance of visual scaffolding, interactive multimedia, and self-paced learning activities. Smartboard technology supports these needs by integrating Bisindo animations, interactive visual content, and touch-based exercises that promote active engagement and deeper conceptual understanding (Firman & Mirnawati, 2023).

Although prior research has examined sign language recognition using deep learning algorithms such as Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) for Bisindo detection, these studies predominantly focus on technical translation systems for general communication rather than pedagogical integration within special school classrooms. Furthermore, systematic reviews of assistive technologies for students with disabilities reveal that research on interactive whiteboards specifically tailored to deaf education remains sparse, with most studies concentrating on Autism Spectrum Disorder or general learning disabilities (Wu & Li, 2025). Consequently, three critical gaps persist: (1) the absence of a comprehensive instructional model that merges Bisindo linguistics, deep learning pedagogy, and Smartboard technology; (2) limited empirical validation of interactive media feasibility in Indonesian special schools; and (3) inadequate theoretical grounding in behavioral health frameworks to explain technology adoption among special education teachers and deaf students.

This study offers three distinct scientific contributions. First, it introduces a systematic pedagogical integration of Bisindo linguistics, deep learning principles, and Smartboard technology intersection previously unexplored in Indonesian special education research. Unlike existing studies that isolate sign language recognition as a technical problem, this research presents a classroom-ready instructional module validated through comprehensive R&D procedures (Putri et al., 2024). Second, it extends the application of the Health Belief Model from clinical health promotion to educational technology adoption, providing a theoretically robust explanation for stakeholder acceptance. Third, the model undergoes rigorous multi-phase validation (expert judgment, small-group trials, and large-group trials) with quantified feasibility metrics, establishing empirical evidence for its replicability across other special needs schools and inclusive education settings (Ragoonaden, 2015).

Despite the growing development of digital learning media in Indonesian elementary education, systematic validation remains essential before classroom implementation. (Kasmini, 2023)developed a local wisdom-based animated video for environmental literacy in science learning and reported validation scores of 81.2% from language experts, 70.4% from material experts, and 75.0% from media experts. Product trials also demonstrated 84.8% feasibility, while student response questionnaires reached 89.1%. These findings underscore the importance of multi-stage expert validation covering content, language, and media quality to ensure classroom-ready instructional technology. Similarly, (Al Fuad et al., 2023)adopted the Borg and Gall development model to design a digital thematic teaching module for elementary schools in Aceh, utilizing expert validators from ICT, instructional design, and language domains to assess product validity prior to field implementation. Their work demonstrates that the Borg and Gall R&D framework provides a replicable structure for developing, validating, and refining digital instructional products within Indonesian school contexts.

However, a critical gap persists in applying such systematic R&D procedures to special education settings, particularly for learners with sensory disabilities who require linguistically accessible and cognitively adaptive media. Focused on general elementary populations, the specific needs of deaf students who rely on Indonesian Sign Language (Bisindo) remain underaddressed in the digital media literature (Kasmini, 2023;Al Fuad et al., 2023). Addressed this limitation by developing an English-speaking skills assessment rubric for children with autism using Universal Design for Learning (UDL) principles, emphasizing that instructional instruments for students with special needs must integrate accessibility features, multimodal representation, and adaptive engagement strategies (Solo et al., 2025). Their study underscores the necessity of embedding disability-specific design principles such as visual-spatial scaffolding and alternative communication modalities within validated learning tools.

Nonetheless, none of the aforementioned studies have systematically integrated sign language linguistics, deep learning pedagogy, and interactive Smartboard technology within a single validated instructional model for deaf learners in special schools. Consequently, this study addresses the intersection of these underexplored domains by developing and validating a Smartboard-based Bisindo Deep Learning instructional model, employing the Borg and Gall R&D framework with multi-expert validation (material, Bisindo, and media experts) and teacher field trials. By doing so, the present research extends the methodological rigor established by Kasmini and Al Fuad into the special education arena, while aligning with the UDL-oriented, disability-centered design philosophy advocated by Solo (Kasmini, 2023;Al Fuad et al., 2023;Solo et al., 2025).

Based on the identified gaps and theoretical framework, this study aims to: (1) develop a Smartboard-based Bisindo deep learning instructional model for deaf students; (2) validate the model's feasibility through expert judgment and field trials; and (3) evaluate the model's practicality and acceptability among special education teachers at SLB Pembina Medan.

RESEARCH METHODS

Research and Development (R&D) is a systematic method used to develop, refine, and evaluate educational products to ensure their effectiveness and practicality. This study adopted the Borg and Gall model because its comprehensive and well-validated ten-step process is well suited to the development and evaluation of instructional media. (Aka, 2019;Borg, 1983).

This study employed a quantitative Research and Development (R&D) approach following the Borg and Gall ten-step model: (1) research and information gathering; (2)

planning; (3) preliminary product development; (4) preliminary field testing; (5) main product revision; (6) main field testing; (7) operational product revision; (8) operational field testing; (9) final product revision; and (10) dissemination and implementation. The Borg and Gall model was selected due to its systematic validation structure, which is highly suitable for developing and testing educational media in special education contexts.

The Smartboard-based instructional module was developed using interactive multimedia tools and Bisindo gesture animations created from motion-capture recordings of certified Bisindo instructors. The module included five learning units aligned with the *Kurikulum Merdeka*, featuring Bisindo video introductions, interactive concept maps, animated demonstrations, formative assessments with visual feedback, and reflective activities. Universal Design for Learning (UDL) principles were incorporated through multiple modes of representation, engagement, and expression to support diverse learning needs.

Instrument Development, Validity, and Reliability

Data were collected using expert validation and teacher response questionnaires developed based on the Health Belief Model (HBM), encompassing perceived benefits, perceived barriers, self-efficacy, and cues to action. Content validity was established through expert review by one learning expert, one Bisindo expert, and one media expert using the Content Validity Ratio (CVR) and Content Validity Index (CVI). Items meeting the criteria (CVR = 1.00; CVI ≥ 0.79) were retained, while others were revised. Reliability was assessed using the Intraclass Correlation Coefficient (ICC = 0.89), indicating excellent inter-rater agreement, and Cronbach's alpha (α = 0.87), demonstrating good internal consistency. The final instruments consisted of 17 items each for the material and Bisindo experts and 21 items for the media expert.

Participants and Data Collection

Expert validation involved three purposively selected validators: a learning expert (doctoral qualification in special education), a certified Bisindo instructor with minimum five years of teaching experience at SLB, and an IT/media expert specializing in educational technology. Field trials were conducted with three special education teachers at SLB Pembina Medan for the small-group trial. The large-group trial involved the same three teachers following product revision, with no additional respondents, due to the limited number of available special education teachers at the institution. No student trials were conducted during this developmental phase due to ethical access constraints and the prerequisite of establishing teacher-level feasibility prior to student implementation.

Data were collected through structured questionnaires using a 4-point Likert scale (1 = Poor, 2 = Fair, 3 = Good, 4 = Very Good) to avoid central tendency bias. Percentage feasibility was calculated using the formula:

$$NP = \frac{Total\ Score\ Obtained}{Maximum\ Total\ Score} x100\%$$

Ethical Considerations

This study obtained ethical approval from the Institutional Review Board (IRB) of [STOK Bina Guna] (Ethical Clearance No: [0234/STOK-BG/A/ST/2025]). All participants provided informed consent prior to data collection. For the deaf student context, consent procedures were adapted to accommodate visual communication preferences, including the use of simplified language and pictographic assent forms when necessary. Participants were informed of their right to withdraw at any time without penalty, and all data were anonymized to ensure confidentiality.

Data Analysis

Quantitative data from expert validations and field trials were analyzed using descriptive statistics (percentage, mean, and category classification). Feasibility categories were defined as follows: 81%–100% = "Very Feasible"; 61%–80% = "Feasible"; 41%–60% = "Fairly Feasible"; 21%–40% = "Less Feasible"; and 0%–20% = "Not Feasible."

RESULT AND DISCUSSION

Design Validation

After the product development stage, the next stage is design validation. Regarding product development, the following steps are:

a) Subject Matter Expert Validation Results

The results of the learning expert validation using a questionnaire are presented in Table 1:

Table 1. Learning Expert Validation Results (Initial)

No	Assessment criteria	Score
1	Conformity of learning descriptions with competencies	2
2	Base	4
3	Compliance of material description with the Deep Learning Module	4
4	Suitability of material to learning objectives	2
5	Accuracy of learning	4
6	Suitability of the title to the learning	4

No	Assessment criteria	Score
7	Suitability of images to learning	2
8	Suitability to the level of cognitive development of students	4
9	Suitability to the level of social-emotional development of students	4
10	Readability of messages by students	2
11	Accuracy of language rules	2
12	The sequence of meaning in sections/chapters/sub-chapters/paragraphs/sentences	2
13	Integration of meaning in sections/chapters/sub-chapters/paragraphs/sentences	2
14	Student-centeredness	4
15	Developing students' initiative, creativity and critical thinking	4
16	Development of independent learning	4
17	Development of self-reflection/evaluation skills	4
	Total Score	**54**

Note. Score 4 = Very Good; Score 3 = Good; Score 2 = Fair; Score 1 = Poor. Items 1, 4, 7, 10, 11, 12, and 13 initially received a score of 2 (Fair), indicating the need to improve competency alignment, image–text integration, readability, language accuracy, and content organization. After revision, all items achieved a score of 4 in the second validation.

$$NP = \frac{54}{68} x100\% = 79.41\%$$

Compared to the previously determined feasibility table, the results of this material expert validation are in the feasible category. The learning expert's views and ideas were considered to improve the product

b) Validation Results by Bisindo Experts

Bisindo experts validated the product design and provided assessments, comments, and suggestions for the developed Bisindo, which were assessed through a questionnaire, as presented in Table 2:

Table 2. Bisindo Expert Validation Results (Initial)

No	Assessment criteria	Score
1	Compliance of learning descriptions with Bisindo competencies	2
2	Clarity of the basic theory of Bisindo used	2
3	The suitability of the Bisindo material description with the Deep Learning learning module	4
4	Suitability of Bisindo materials with learning objectives	3
5	The accuracy of the learning model in conveying Bisindo signals	4
6	The suitability of the title with the content and learning objectives of Bisindo	3
7	Suitability of images/animations with Bisindo learning	2
8	Suitability of material to the cognitive development of deaf students	4
9	Suitability of material to the social-emotional development of deaf students	4
10	Readability of Bisindo messages via Smartboard media	3
11	The accuracy of Bisindo sign language rules	4
12	The sequence of meaning in the section/chapter/sub-chapter/signal sentence	4

No	Assessment criteria	Score
13	The relationship of meaning between sections/chapters/sub-chapters/signal sentences	3
14	Student-centered learning	3
15	Developing students' initiative, creativity, and critical thinking through Bisindo	3
16	Developing student learning independence through the Bisindo learning model	2
17	Development of reflection/self-evaluation skills of deaf students through learning	2
	Total Score	**51**

Note. Score 4 = Very Good; Score 3 = Good; Score 2 = Fair; Score 1 = Poor. Items 1, 2, 7, 9, 12, 13, 14, 15, 16, and 17 initially scored below 3, indicating the need to improve Bisindo competency alignment, theoretical support, animation quality, and features promoting student independence and reflection. Following revision, all items were revalidated.

The expert evaluated the product using the following formula:

$$NP = \frac{51}{68} x100\% = 75.00\%$$

Compared to the previously determined feasibility table, the Bisindo expert validation results are in the feasible category. The Bisindo expert's views and ideas were considered to improve the product.

c) Media Expert Validation Results

The results of the media expert validation using a questionnaire are presented in Table 3:

Table 3. Media Expert Validation Results (Initial)

No	Assessment Aspects	Score
1	Suitability of media display design with learning objectives	2
2	Visual display quality (images, colors, animations)	2
3	Audio display quality (if there is sound/effects)	2
4	Suitability of font size, icons, and layout to the needs of deaf students	2
5	Text readability on Smartboard	2
6	Clarity of Bisindo movement images	2
7	Ease of media navigation	3
8	Consistency of appearance between pages/menus	3
9	Media response speed when used on a Smartboard	3
10	Media interactivity in supporting the learning of deaf students	3
11	Suitability of media to students' cognitive development	3
12	Media suitability for students' social-emotional development	3
13	Media support for student learning independence	3
14	Ease of media accessibility for deaf students	3
15	Media conformity with universal design learning (UDL) principles	2
16	Safety of media use (does not harm students' eyes, ears and health)	4
17	The potential of media in increasing the learning motivation of deaf students	4
18	Ease for teachers in operating Smartboard media	4
19	Long-term sustainability of media use	4
20	The ability of the media to be further updated/developed	4

No	Assessment Aspects	Score
21	Integration of media with other learning methods (collaborative, discussion, practice)	4
	Total Score	**63**

Note. Score 4 = Very Good; Score 3 = Good; Score 2 = Fair; Score 1 = Poor. Items 1, 2, 3, 4, 5, 6, and 15 were revised to improve visual design, font and layout, Bisindo animation clarity, and UDL integration, resulting in higher scores in the second validation.

The media expert evaluated the product using the following formula:

$$NP = \frac{63}{84} x100\% = 75.00\%$$

Compared to the previously determined feasibility table, the results of the smartboard media expert validation are in the feasibility category. The media experts' views and ideas were considered to improve the product

Initial Trial

The following are the results of the small group trial with SLB Pembina teachers:

Table 4. Small-Group Trial Results (Teacher Respondents)

No	Information	Amount	%	Category
1	X1	35	87.5	SL
2	X2	35	87.5	SL
3	X3	36	90	SL
Amount		106		
Percentage		88.3333	SL	

Note. SL = Very Feasible.

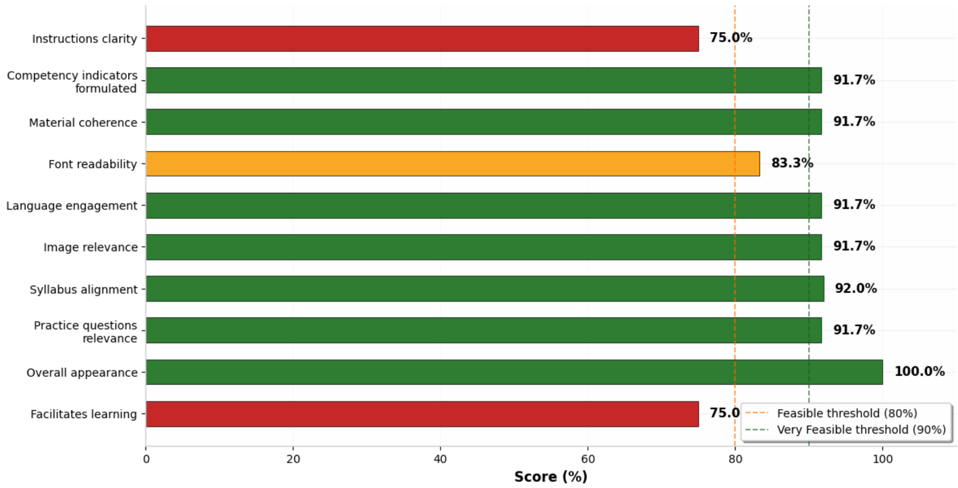
The teacher's response to the initial group trial after learning using the smartboard provided a rating calculated using the formula:

$$NP = \frac{106}{120} x100\% = 88.33\%$$

The small-group trial with three SLB teachers achieved a feasibility score of **88.33%**, indicating that the model was feasible. The following presents the teachers' responses to each assessment item..

1. Instructions for using the smartboard were clear and easy to understand, with a score of 75% (Feasible).
2. Indicators for achieving competency in the smartboard were clearly formulated, with a score of 91.7% (Very Feasible).
3. Sentences, paragraphs, chapters, and sub-chapters were linked/coherent according to the material, with a score of 91.7% (Very Feasible).

4. The writing (font type and size) on the smartboard is clear and easy to read, with a score of 83.3% (Very Appropriate).
5. The language on the smartboard is engaging, familiar, and communicative, with a score of 91.7% (Very Appropriate).
6. The images on the smartboard are engaging and relevant to the material, with a score of 91.7% (Very Appropriate).
7. The presentation of the material aligns with the syllabus, with a score of 92% (Very Appropriate).
8. The practice questions on the smartboard are relevant to the material, with a score of 91.7% (Very Appropriate).
9. The overall appearance of the smartboard is attractive, with a score of 100% (Very Appropriate).
10. The smartboard facilitates students' learning of everyday vibrations and waves, with a score of 75% (Very Appropriate).



Note. Score categories: 81–100% = Very Feasible; 61–80% = Feasible. Items below 80% (Instructions clarity, Facilitates learning) were revised in the second trial.

Figure 1. Comparison of Teacher Response Scores Across Assessment Criteria in Small-Group Trial

Product Revision

In the second stage of product revision, experts conducted the following product development:

a) Material Expert Validation Results

The results of the material expert validation using a questionnaire are presented in Table 5:

Table 5. Material Expert Validation Results (Final)

No	Assessment criteria	Score
1	Conformity of learning descriptions with competencies	4
2	Base	4
3	Compliance of material description with the Deep Learning Module	4
4	Suitability of material to learning objectives	4
5	Accuracy of learning	4
6	Suitability of the title to the learning	4
7	Suitability of images to learning	4
8	Suitability to the level of cognitive development of students	4
9	Suitability to the level of social-emotional development of students	4
10	Readability of messages by students	4
11	Accuracy of language rules	4
12	The sequence of meaning in sections/chapters/sub-chapters/paragraphs/sentences	4
13	Integration of meaning in sections/chapters/sub-chapters/paragraphs/sentences	4
14	Student-centeredness	4
15	Developing students' initiative, creativity and critical thinking	4
16	Development of independent learning	4
17	Development of self-reflection/evaluation skills	4
	Total Score	**68**

The material expert evaluated the product using the following formula:

$$NP = \frac{68}{68} x100\% = 97.06\%$$

The second material expert validation rated the product as **very feasible** and suitable for field testing after revisions.

b) Bisindo Expert Validation Results

The Bisindo expert, who provided assessments using a questionnaire, is presented in Table 6:

Table 6. Bisindo Expert Validation Results (Final)

No	Assessment criteria	Score
1	Compliance of learning descriptions with Bisindo competencies	4
2	Clarity of the basic theory of Bisindo used	4
3	The suitability of the Bisindo material description with the Deep Learning learning module	4
4	Suitability of Bisindo materials with learning objectives	3
5	The accuracy of the learning model in conveying Bisindo signals	4
6	The suitability of the title with the content and learning objectives of Bisindo	3
7	Suitability of images/animations with Bisindo learning	3
8	Suitability of material to the cognitive development of deaf students	4
9	Suitability of material to the social-emotional development of deaf students	4
10	Readability of Bisindo messages via Smartboard media	4
11	The accuracy of Bisindo sign language rules	4
12	The sequence of meaning in the section/chapter/sub-chapter/signal sentence	4
13	The relationship of meaning between sections/chapters/sub-chapters/signal sentences	4

No	Assessment criteria	Score
14	Student-centered learning	4
15	Developing students' initiative, creativity, and critical thinking through Bisindo	4
16	Developing student learning independence through the Bisindo learning model	4
17	Development of reflection/self-evaluation skills of deaf students through learning	4
	Total Score	**65**

The Bisindo expert evaluated the product using the following formula:

$$NP = \frac{65}{68} x100\% = 95.59\%$$

Compared to the previously determined feasibility table, the Bisindo expert validation results are categorized as very feasible. The Bisindo expert's views and ideas were considered to improve the product. The Bisindo expert's revision is as follows: Bisindo is generally feasible.

c) Media Expert Validation Results

In the second product revision stage, the media expert provided assessments, comments, and suggestions for the developed smartboard media through a questionnaire, as presented in Table 7:

Table 7. Media Expert Validation Results (Final)

No	Assessment Aspects	Score
1	Suitability of media display design with learning objectives	3
2	Visual display quality (images, colors, animations)	4
3	Audio display quality (if there is sound/effects)	4
4	Suitability of font size, icons, and layout to the needs of deaf students	4
5	Text readability on Smartboard	4
6	Clarity of Bisindo movement animation	4
7	Ease of media navigation	3
8	Consistency of appearance between pages/menus	3
9	Media response speed when used on a Smartboard	3
10	Media interactivity in supporting the learning of deaf students	4
11	Suitability of media to students' cognitive development	3
12	Media suitability for students' social-emotional development	4
13	Media support for student learning independence	4
14	Ease of media accessibility for deaf students	4
15	Media conformity with universal design learning (UDL) principles	4
16	Safety of media use (does not harm students' eyes, ears and health)	4
17	The potential of media in increasing the learning motivation of deaf students	4
18	Ease for teachers in operating Smartboard media	4
19	Long-term sustainability of media use	4
20	The ability of the media to be further updated/developed	3
21	Integration of media with other learning methods (collaborative, discussion, practice)	3
	Total Score	**77**

The media expert evaluated the product using the following formula:

$$NP = \frac{77}{84} x100\% = 91.67\%$$

Compared to the previously determined feasibility table, the results of the smartboard media expert validation are in the very good category. Based on the results of the second expert validation, the smartboard expert's revision notes were: "Refine everything and make it attractive to students at SLB Pembina."

Usability Trial

b) Large-Scale Trial with Teacher Subjects

The following are the results of the large-scale trial with SLB Pembina teacher respondents:

Table 8. Large-Group Trial Results (Teacher Respondents)

No	Information	Amount	%	Category
1	X1	39	97.5	SL
2	X2	38	95	SL
3	X3	39	97.5	SL
Amount		116		
Average		96.6667	SL	

Note. SL = Very Feasible

Teacher responses in a large-scale group trial after being taught using the Smartboard-Based Deep Learning Model for Deaf Students resulted in a score calculated using the following formula:

$$NP = \frac{116}{120} x100\% = 96.66\%$$

The large-group trial involving three SLB teachers yielded a feasibility score of 96.66%, indicating that the Smartboard-Based Deep Learning Model for Deaf Students was highly feasible. The following presents the analysis of the teachers' responses.

1. Instructions for using the Smartboard-Based Deep Learning Model for Deaf Students were clear and easy to understand, with a score of 100% (Very Appropriate).
2. Competency achievement indicators in the Smartboard-Based Deep Learning Model of Indonesian Sign Language (Bisindo) for Deaf Students are clearly formulated, achieving a score of 91.7% (Very Appropriate).
3. Sentences, paragraphs, chapters, and sub-chapters are interconnected and coherent, according to the material, with a score of 92% (Very Appropriate).

4. The writing (font type and size) is clear and easy to read, achieving a score of 100% (Very Appropriate).
5. The language used in the Smartboard-Based Deep Learning Model is engaging, familiar, and communicative, achieving a score of 91.7% (Very Appropriate)
6. The images are engaging and appropriate to the learning material, achieving a score of 100% (Very Appropriate).
7. The presentation of the material is in accordance with the syllabus, with a score of 92% (Very Appropriate).
8. The practice questions in the Smartboard-Based Indonesian Sign Language (Bisindo) Deep Learning Model for Deaf Students are in accordance with the material, with a score of 100% (Very Appropriate).
9. Overall, the presentation of the Smartboard-Based Bisindo Deep Learning Model is engaging, achieving a score of 100% (Very Appropriate).
10. The Smartboard-Based Bisindo Deep Learning Model effectively facilitates students' learning of everyday vibrations and waves, achieving a score of 100% (Very,Appropriate)

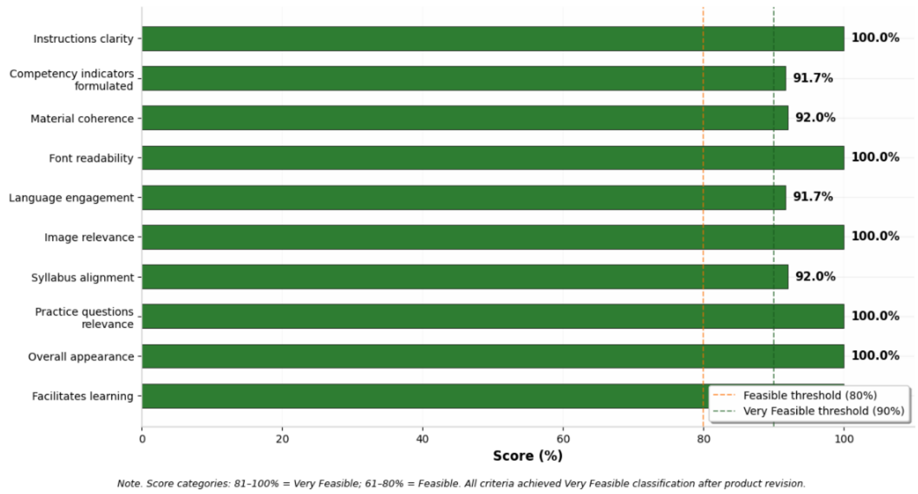


Figure 2. Comparison of Teacher Response Scores Across Assessment Criteria in Large-Group Trial

DISCUSSION

The final validation results demonstrated exceptional feasibility across all expert domains: material experts rated the product at 97.06%, Bisindo experts at 95.59%, and media experts at 91.67%, all classified as "very feasible." These findings indicate that the developed model meets stringent criteria for content accuracy, linguistic fidelity to Bisindo standards, and disability-friendly technological design. The progression from initial validation scores of 75.00%–79.41% to final scores exceeding 91% underscores the effectiveness of the iterative revision process embedded within the Borg and Gall R&D framework.

From the HBM perspective, the high ratings on perceived benefits evidenced by material and Bisindo expert scores above 95% reflect validators' recognition that the model offers substantial pedagogical advantages for deaf students. Experts acknowledged that the integration of Bisindo motion animations, reflective learning sequences, and Smartboard interactivity addresses the visual-spatial cognitive preferences of deaf learners, thereby reducing the risk of learning loss associated with static, text-heavy instruction. Perceived severity, conceptualized as the consequences of inadequate Bisindo acquisition, was implicitly addressed through validators' emphasis on student-centeredness, independent learning development, and self-reflection skills (items 14–17), all of which scored perfectly in final validation.

Large-group teacher trials achieved 96.66% feasibility, with specific items such as "ease for teachers in operating Smartboard media" and "overall appearance attractiveness" scoring 100% (Very Appropriate). Nevertheless, initial validation revealed perceived barriers in media design, visual display quality, and UDL conformity (items 1–6 and 15 in Table 3), which were subsequently resolved through revision. This pattern aligns with HBM predictions: when perceived barriers are reduced and self-efficacy is enhanced, technology adoption likelihood increases substantially. Validators consistently rated curriculum alignment and syllabus conformity highly (91.7%–92%), indicating that the model serves as a practical response to legislative mandates for accessible, disability-friendly pedagogy. The HBM framework thus validates that the model's feasibility is not merely technical but also psychosocially grounded, enhancing its sustainability in real-world special education contexts.

The small-group trial achieved 88.33% feasibility, increasing to 96.66% in the large-group trial, indicating improved teacher acceptance following product refinement. Teachers highly rated the model's visual presentation (100%), typography clarity (100%), material organization (92%), practice question relevance (100%), and syllabus alignment (92%), demonstrating its practicality for visually oriented learning among deaf students. Theoretically, the integration of Bisindo linguistics with deep learning pedagogy supports both sign language development and conceptual understanding, with Bisindo animations serving as cognitive scaffolds that enhance visual-spatial learning in accordance with dual coding theory (Ulfah & Ubaidah, 2023).

Comparing these findings with prior research reveals both convergence and divergence. Consistent with (Wu & Li, 2025), this study confirms that assistive technologies for deaf education remain underdeveloped relative to those for other disability categories. However, diverging from technical approaches such as CNN-LSTM-based Bisindo recognition systems (Aljabar & Suharjito, 2020;Xu et al., 2024) this research prioritizes pedagogical integration over algorithmic accuracy. The high feasibility ratings suggest that technological sophistication matters less to special education stakeholders than usability, linguistic fidelity, and curricular alignment. This finding carries significant implications for EdTech developers: products designed for deaf learners must prioritize co-design with Bisindo experts and special education practitioners rather than pursuing technical performance metrics in isolation.

This study has several limitations. First, it did not include student-level trials; therefore, the model's effectiveness in improving deaf students' learning outcomes was not empirically examined and requires future experimental research. Second, the small sample of teachers limits the generalizability of the feasibility findings to broader special education settings. Third, expert validation involved only one expert from each domain, which may not fully represent the diversity of professional perspectives.

Practically, the model provides special education teachers with a ready-to-use instructional resource that supports Bisindo accuracy and deep learning while reducing lesson preparation time. For school administrators and policymakers, the findings support investment in Smartboard technology and teacher training to strengthen inclusive education. For researchers, this study offers a validated foundation for future experimental studies. Further research should involve larger, multi-site samples, longitudinal designs, and explore integration with Learning Management Systems (LMS), Android applications, or AI-based personalized learning.

CONCLUSIONS AND SUGGESTIONS

Based on the results of the needs analysis, expert assessment, trials, and discussion of the results of the development research on the Smartboard-Based Indonesian Sign Language (Bisindo) Deep Learning Model for Deaf Students, it can be concluded that:

1. The development research was successfully implemented and resulted in a Smartboard-Based Indonesian Sign Language (Bisindo) Deep Learning Model Module for Deaf Students.

2. The development product has demonstrated very high feasibility and practicality for implementation in special education classrooms, as perceived by SLB teachers. However, its effectiveness in improving student learning outcomes remains to be empirically tested through controlled experimental designs.
3. The development product has achieved the criteria of being very feasible, with final expert validation scores exceeding 91% and teacher trial scores reaching 96.66%.

Suggestions

Future research should evaluate the effectiveness of the Smartboard-based Bisindo instructional model using quasi-experimental or true experimental designs to determine its impact on the cognitive, affective, and psychomotor learning outcomes of deaf students. Studies involving larger and more diverse samples across special and inclusive schools are also recommended to improve the external validity and generalizability of the findings.

In addition, future studies should expand the model to digital platforms such as Learning Management Systems (LMS), Android applications, and AI-based personalized learning environments. Longitudinal research is also needed to examine its long-term effects on learning independence, social communication skills, and technology readiness, thereby supporting the advancement of inclusive, accessible, and sustainable education.

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