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Developing Constructivism-Based Multimedia E-Module for Adaptive Physical Education of Deaf Students

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Abstract

Adaptive physical education for deaf students in Indonesian special schools still relies on verbal instruction and printed materials that poorly match these learners' visual characteristics. This study developed and tested the feasibility, practicality, and effectiveness of a multimedia-based adaptive physical education e-module grounded in a constructivist approach. A research and development design with the 4D model (define, design, develop, limited disseminate) was applied, involving 52 deaf students in grades VII–VIII and four teachers across four special schools in Medan, three expert validators, and a one-group pretest-posttest effectiveness test. Expert validation averaged 92.53% (very valid): 93.60% content, 92.00% media, and 92.00% special education. The small-group trial yielded practicality ratings of 91.00% from students and 88.75% from teachers (very practical). In the large-group trial, understanding of adaptive movement increased from a pretest mean of 52.35 to 78.65, with an N-Gain of 0.552 (moderate), $t(51) = 27.641$, $p < 0.001$, and Cohen's $d = 3.37$; motivation rose by 34.72% and engagement from 58.30% to 87.50%. As the first e-module integrating sign-language-embedded multimedia, three-level constructivist scaffolding, and comprehensive adaptive physical education content for deaf learners, the product proved valid, practical, and effective.

Keywords: adaptive physical education; constructivism; deaf students; e-module; multimedia learning

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A. Introduction

Physical education plays a distinctive role in educating children with disabilities, supporting emotional, social, and intellectual development alongside physical fitness. For the roughly 34 million children worldwide with disabling hearing loss, meaningful movement experiences are constrained more by communication barriers than by physical capacity (World Health Organization [WHO], 2021). Adaptive physical education has thus emerged as an essential service, modifying content, equipment, rules, and environments so students with special needs can participate safely. Evidence continues to accumulate on its developmental benefits (Sukriadi & Arif, 2021; Petrov et al., 2025; Manojlovic et al., 2023), yet implementation remains uneven, and students with hearing impairment remain among the most underserved.

Deaf students face barriers that differ qualitatively from those of hearing peers. Because conventional sport instruction relies on whistles, verbal cues, and spoken explanation, students who cannot access auditory information routinely miss the instructional core of the lesson (Luckner et al., 2001), which depresses participation, weakens social interaction, and erodes confidence in movement settings. Visual teaching strategies have long been recommended as compensation, but observational evidence shows they are applied inconsistently, even though audiovisual materials support knowledge acquisition and participation (Akay, 2021) and deaf and hard-of-hearing learners show a marked preference for visual and kinesthetic modalities (Podkamennyy et al., 2025). In practice, however, instruction remains dominated by teacher demonstration and whole-class verbal routines, leaving deaf students dependent on fleeting visual information rarely designed with them in mind.

Multimedia learning theory offers a principled response. The cognitive theory of multimedia learning holds that people learn more deeply from words and pictures than words alone, provided the design respects working memory through coherence, signaling, segmenting, and modality principles (Mayer, 2021). For deaf learners this must be reinterpreted: since the auditory channel is unavailable, the visual channel must carry both pictorial and verbal information without overload. Recent work supports this reinterpretation: video tutorials combining images and text improve comprehension for deaf and hard-of-hearing students (Al-Fannah et al., 2022), technology integration is linked to gains in performance, collaboration, and learning experience (Rehman et al., 2024), immersive visual-spatial technologies improve retention in sign language learning (Berrezueta-Guzman et al., 2025), machine-learning applications enable interactive sign language practice (Orovwode et al., 2024), and digital-intelligent technologies are reshaping how movement skills are taught within physical education itself (Li et al., 2025).

Parallel to these advances, constructivism has become the dominant paradigm for meaningful, student-centered instruction, holding that learners actively build knowledge by interpreting new experiences against prior understanding (Özer Şanal & Erdem, 2023). Two traditions inform practice: Piaget's cognitive constructivism, emphasizing assimilation, accommodation, and direct experience, and Vygotsky's social constructivism, which locates learning within the zone of proximal development where graduated scaffolding enables performance beyond independent capability (Vygotsky, 1978). In such environments, technology functions as a microworld supporting exploration, hypothesis testing, collaboration, and reflection (Jonassen, 1999), and constructivism-led assistive technology has been shown to improve achievement, collaboration, self-regulation, and metacognitive awareness among deaf learners (Abiatal & Howard, 2020). Physical education, with its embodied cycle of observation, imitation, exploration, and reflection, is a natural but rarely exploited arena for constructivist design.

Three streams of prior research frame the gap this study addresses. The first developed digital learning media for adaptive physical education: the TISERA application provided sign-supported content for hearing-impaired students (Andriyani et al., 2021), and flipbook-based practicum modules proved attractive for online learning (Erianti et al., 2022). The second produced e-modules for deaf learners in academic subjects, showing that accessibility-driven design enhances independent learning (Utami et al., 2023). The third applied interactive multimedia to inclusive education more broadly, confirming that universal-design modules raise comprehension and engagement (Badiah & Kurniawan, 2025). None, however, has simultaneously integrated comprehensive adaptive physical education content, multimedia design grounded in the cognitive theory of multimedia learning, universal design accessibility, and a constructivist instructional process within a single product for deaf students.

The gap is particularly consequential in Indonesia, where the inclusive education agenda has expanded faster than supporting resources. Teachers report struggling with inadequate training, scarce resources, and socio-cultural barriers (Rofiah et al., 2023); physical education teachers often lack specialized backgrounds and must improvise without specialized materials (Gandasari, 2023) or the support structures needed to facilitate meaningful participation (Bertills & Björk, 2024). Indonesian e-module research has grown rapidly in mainstream subjects (Almaas et al., 2025; Haka et al., 2021; Mahendri et al., 2023), yet products for deaf students in physical education remain almost absent. A preliminary needs assessment in four special schools in Medan confirmed this pattern locally: no school possessed an adaptive physical education e-module, 91% of students struggled to comprehend movement instruction, and 100% of respondents identified an urgent need for visual multimedia materials.

Closer inspection of the most relevant prior products clarifies what remains undone. TISERA (Andriyani et al., 2021) embedded sign language videos and games but did not operationalize constructivist principles or differentiate by motor ability. Utami et al.'s (2023) e-module fostered learning independence for hearing-impaired students but addressed academic rather than psychomotor content. Badiah and Kurniawan's (2025) module applied universal design convincingly but targeted visually impaired university students. Differentiated e-modules have been validated in mainstream primary education (Liu et al., 2024) and self-regulated learning modules have strengthened teacher competencies (Ganendra et al., 2025), but neither crosses into adaptive physical education for deaf learners. The intersection of these proven design elements within one product therefore constitutes a genuine and unoccupied research niche.

Responding to this niche, the present study produced a web-responsive multimedia e-module operationalizing the state of the art in four respects. First, instruction is delivered entirely visually: demonstration videos carry BISINDO sign-language interpretation, slow-motion playback, frame-by-frame navigation, and dynamic highlighting, with no dependence on audio narration. Second, the design applies the coherence, signaling, segmenting, and contiguity principles of multimedia learning (Mayer, 2021) with high-contrast, WCAG 2.1 AA-compliant typography. Third, following Universal Design for Learning guidelines (CAST, 2018), each unit offers three graduated levels of motor difficulty guided imitation, icon-based instruction, and independent exploration so students enter tasks at their own readiness level. Fourth, constructivist pedagogy is embedded throughout: diagnostic visual quizzes activate prior knowledge, interactive simulations support self-paced exploration, paired practice enables collaboration, immediate visual feedback sustains formative evaluation, and pictorial reflection sheets close each unit with self-assessment.

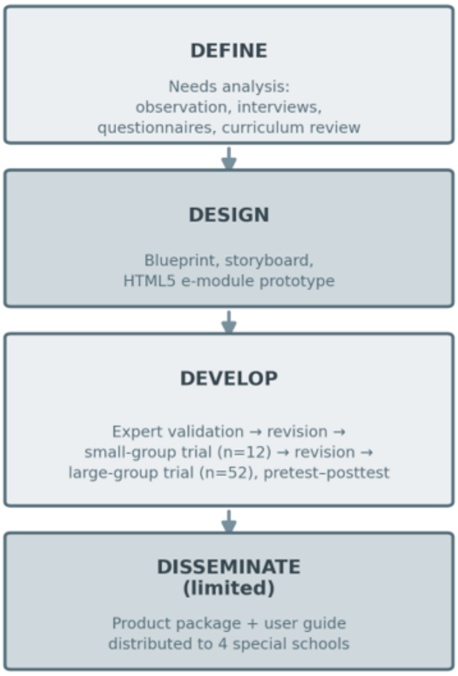
The novelty of this study is threefold. To the authors' knowledge, it is the first R&D study to integrate a constructivist instructional framework, sign-language-embedded multimedia, and comprehensive adaptive physical education content including sound-independent, visual-cue-based rhythmic activities within a single validated e-module for deaf junior-secondary students. It is also the first to demonstrate the feasibility of three-level motor differentiation for this population in the Indonesian special school context. Finally, unlike prior media studies reporting only validation or attractiveness data, this study subjects the product to a complete development cycle culminating in effectiveness testing on movement understanding, learning motivation, and student engagement.

Guided by the four stages of the 4D development model, the study pursued four objectives: (1) analyze the needs of deaf students and physical education teachers in special schools in Medan as the foundation for product development; (2) design a multimedia-based adaptive physical education e-module consistent with deaf students' visual-kinesthetic learning characteristics and constructivist principles; (3) determine the e-module's validity and practicality through expert judgment and limited trials; and (4) examine its effectiveness in improving students' understanding of adaptive movement, learning motivation, and engagement.

B. Methods

1. Research Design

This study employed a research and development (R&D) approach aimed at producing and testing a multimedia-based adaptive physical education e-module for deaf students. Development followed the 4D model define, design, develop, and disseminate which provides a systematic yet flexible structure for creating instructional products for exceptional learners (Thiagarajan et al., 1974). Owing to time and resource constraints, the disseminate stage was implemented as a limited dissemination in which the final product, access links, and user guides were distributed to the four participating schools rather than released at scale; this stage is therefore more accurately characterized as pilot implementation. The effectiveness test embedded in the develop stage used a one-group pretest-posttest design. Because this pre-experimental design has no control group, internal validity threats such as history and maturation cannot be fully excluded; effectiveness claims are accordingly interpreted with caution and triangulated against observation and user response data. The overall research flow is presented in Picture 1.



Picture 1. Research flow based on the 4D development model

2. Participants and Research Site

The research was conducted in four special schools in Medan and its surrounding area, Indonesia: SLB Negeri Pembina Medan, SLB Negeri 1 Binjai, SLB Mutiara Hati Medan, and SLB ABC Melati Aisyiyah Medan. The schools were selected through purposive sampling because each runs an adaptive physical education program and enrolls an adequate population of deaf students. Participants were 52 deaf students in grades VII–VIII (25 boys and 27 girls, aged 12–15 years) and four physical education teachers. Inclusion criteria were medically documented hearing impairment, normal intellectual functioning, and the absence of severe additional physical disability. Most students (88.46%) used BISINDO as their primary daily communication mode, 94.23% exhibited a visual-kinesthetic learning style, and 23.08% had residual hearing. Three experts served as validators: a lecturer in adaptive physical education (content expert), a lecturer in learning technology (media expert), and a lecturer in special education (special education expert).

3. Research Instruments

Seven instruments were developed. Three expert validation questionnaires assessed content (25 items, five-point scale), media (30 items, five-point scale), and special education appropriateness (20 items, four-point scale). Four field instruments comprised a student response questionnaire (17 items), a teacher response questionnaire (16 items), a learning motivation questionnaire (20 items, four-point scale), and a student engagement observation sheet (15 items, four-point scale). Movement understanding was measured with a visually based written test administered as pretest and posttest (maximum score 100). Empirical validity of the field instruments was examined through Pearson product-moment correlation of each item against the total score on a trial sample of 20 non-sample students (critical r = 0.444) and on the full sample (critical r = 0.273); all items exceeded the critical values (r = 0.284–0.820) and none were dropped. The expert questionnaires were validated through expert judgment, yielding Aiken's V coefficients above 0.80. Reliability, estimated with Cronbach's alpha, ranged from 0.835 to 0.891 across instruments, indicating high internal consistency.

4. Data Collection

Data were gathered through

observation, semi-structured interviews, questionnaires, tests, and documentation. During the define stage, four weeks of participant observation documented actual adaptive physical education practices, while interviews with all four teachers and twenty purposively selected students assisted by a BISINDO interpreter explored instructional barriers and media needs; curriculum documents were reviewed to map content against the operational curriculum of the schools. The design stage translated these findings into a product blueprint, storyboard, and initial prototype built as an interactive flipbook-based HTML5 web application. The develop stage proceeded iteratively: expert validation and revision, a small-group trial with 12 students over three meetings, further revision, and a large-group trial involving all 52 students across four weeks with two meetings per week. The pretest and posttest were administered immediately before and after the large-group trial, and motivation and engagement were measured during the intervention. The limited disseminate stage delivered the product package and user guide to the four schools.

5. Data Analysis

Qualitative data from observations and interviews were analyzed thematically through data reduction, data display, and conclusion drawing. Quantitative feasibility and practicality scores were converted into percentages of the maximum possible score and interpreted using conventional category intervals, with 86–100% denoting the highest category (very valid or very practical). Normality of the pretest and posttest distributions was tested with the Shapiro–Wilk test. The effectiveness hypothesis was examined with a paired sample t-test after normality was confirmed (pretest $p = 0.082$; posttest $p = 0.128$). Practical significance was quantified with the normalized gain (N-Gain), classified as high ($g \geq 0.70$), moderate ($0.30 \leq g < 0.70$), or low ($g < 0.30$) following Hake (1998), and with Cohen's d, for which values above 0.80 indicate a large effect (Cohen, 1988).

6. Ethical Considerations

Research permits were obtained from the education authorities and the principals of the four schools. Because participants were minors with hearing impairment, informed consent was secured through school representatives, teachers, and parents with BISINDO-mediated explanation. Participation was voluntary, responses were anonymized, and all data were used solely for research purposes.

C. Result and Discussion

Result

1. Needs Assessment

Four weeks of observation showed that adaptive physical education in the four schools remained conventional and teacher-centered. Approximately 75% of lesson time was dominated by teacher explanation and demonstration, and only 18.75% of observed sessions used any visual media. No school used interactive digital media; the available materials were worn printed posters without sequential visual guidance. Thematic analysis of the teacher interviews produced three convergent themes: verbal communication barriers as the primary obstacle, an urgent need for replayable movement videos, and the absence of systematic adaptive teaching guides. Student interviews reinforced these themes 95% of the interviewed students reported difficulty understanding movement explanations, 90% preferred learning through video and pictures, and 85% found conventional lessons monotonous. The needs questionnaire administered to all teachers and students confirmed a very high demand for development, as summarized in Table 1.

Table 1. Results of the Need Assessment Questionnaire

Indicator	Percent	Category
Need for digital learning media	100	Very High

Indicator	Percent	Category
Need for multimedia-based e-module	100	Very High
Urgency of developing an adaptive PE e-module	100	Very High
Students experiencing learning difficulties	94	Very High
Difficulty understanding movement instruction	91	Very High
Need for sign language video	91	Very High
Difficulty with abstract concepts	88	Very High
Need for visual images and animations	88	Very High
Teachers' difficulty creating visual media	85	Very High
Students' preference for interactive learning	82	High

2. Product Design and Expert Validation

The resulting e-module is a web-responsive HTML5 application that runs on computers, tablets, and smartphones and supports offline caching. It organizes the core scopes of adaptive physical education fundamental motor skills (locomotor, non-locomotor, and manipulative) and visual-cue-based adaptive rhythmic activities into six learning units. Each unit contains learning objectives, contextual reading, BISINDO-interpreted demonstration videos, step-by-step animation, exploration activities, interactive quizzes, and reflection sheets, complemented by a teacher guide covering instructional scenarios and observation rubrics. All three experts rated the e-module in the highest category, with an average feasibility percentage of 92.53% (Table 2). Revisions made in response to expert advice included three-level movement variations with amplitude illustrations, an ear-icon panel for students with residual hearing, contextual reading text beneath each illustration, simplified sentence structures, inclusive cover characters, brighter high-contrast palettes, adjustable font sizes, haptic tempo feedback, a parent guidance module, and the removal of decorative elements to reduce extraneous cognitive load.

Table 2. Recapitulation of Expert Validation Results

Validator	Items	Score	Percent	Category
Content expert	25	117	93.60	Very Valid
Media expert	30	138	92.00	Very Valid
Special education expert	20	92	92.00	Very Valid
Average	75	347	92.53	Very Valid

3. Small-Group Trial

The small-group trial involved 12 students and four teachers over three meetings of 70 minutes each. Student responses to the revised product averaged 91.00%, falling in the very practical category (Table 3); the clarity of instructions and the accessibility of the sign language videos received the highest ratings, while navigation and text size received the lowest, prompting minor interface adjustments. Teacher responses averaged 88.75%, also in the very practical category. Teachers judged the e-module easy to operate without intensive technical training and recommended extending the materials to other grade levels and adding a printed quick-start guide, both of which were accommodated in the final revision.

Table 3. Student Response Results in the Small-Group Trial

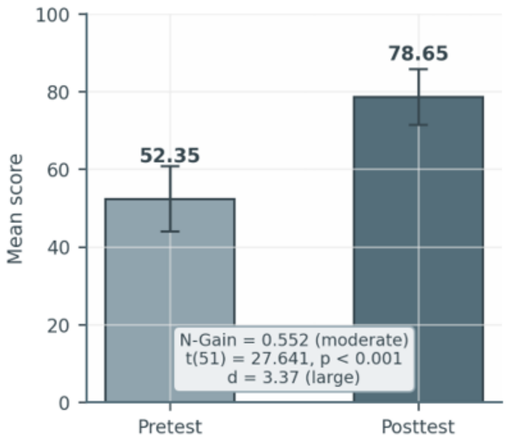
Aspect	Mean	Percent	Category
Display attractiveness	4.58	91.67	Very Practical
Ease of use	4.42	88.33	Very Practical
Content clarity	4.50	90.00	Very Practical
Motivation enhancement	4.67	93.33	Very Practical
Learning usefulness	4.58	91.67	Very Practical
Average	4.55	91.00	Very Practical

4. Large-Group Trial: Movement Understanding

After four weeks of implementation (eight meetings), students' understanding of adaptive movement improved markedly. The posttest mean of 78.65 exceeded the pretest mean of 52.35 by 26.30 points, and the dispersion of scores narrowed, indicating that lower-achieving students converged upward (Table 4; Picture 2). The Shapiro–Wilk test confirmed that both distributions were normal (pretest $p = 0.082$; posttest $p = 0.128$), satisfying the assumption for parametric analysis. The paired sample t-test showed a statistically significant difference, $t(51) = 27.641$, $p < 0.001$. The normalized gain reached 0.552, classified as moderate, and the effect size reached 3.37, far above the 0.80 benchmark for a large effect (Table 5).

Table 4. Descriptive Statistics of Pretest and Posttest Scores

Statistic	Pretest	Posttest
N	52	52
Mean	52.35	78.65
Median	51.00	79.00
Mode	48	80
Std. Deviation	8.42	7.18
Minimum	38	65
Maximum	68	92



Picture 2. Comparison of pretest and posttest mean scores with standard deviations

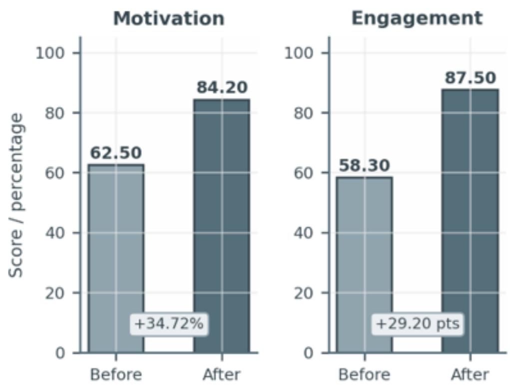
Table 5. Paired Sample t-Test and N-Gain Results

Parameter	Value	Interpretation
Mean difference	26.30 (SD = 6.85)	—

Parameter	Value	Interpretation
t	27.641	—
df	51	—
Sig. (2-tailed)	< 0.001	Significant
N-Gain	0.552	Moderate
Cohen's d	3.37	Large

5. Learning Motivation and Student Engagement

Learning motivation increased from 62.50 (moderate category) before implementation to 84.20 (high category) afterwards, a gain of 21.70 points or 34.72%. The strongest gains appeared in items concerning interest in the material and willingness to attempt movement variations independently. Student engagement rose from 58.30% to 87.50%, with the highest engagement observed when students watched the demonstration videos (94.20%) and worked on the interactive quizzes (91.30%). Observersnoted that students spontaneously replayed video segments, imitated movements without being instructed, and helped peers interpret the visual cues behaviors that were rarely seen during conventional instruction (Picture 3).



Picture 3. Improvement of learning motivation and student engagement

Discussion

1. The Urgency of Multimedia-Based Adaptive Physical Education for Deaf Students

The needs assessment documented a structural mismatch between how adaptive physical education is taught and how deaf students learn. Instruction remained overwhelmingly verbal and demonstrative, while the learner population was almost entirely visual-kinesthetic. This finding mirrors the national picture: Indonesian special school teachers commonly deliver adaptive lessons without specialized materials and acknowledge that their competencies require systematic upgrading (Gandasari, 2023), and inclusive education initiatives continue to be hampered by scarce learning resources (Rofiah et al., 2023). The 100% demand for a multimedia e-module in this study exceeds the urgency levels typically reported in mainstream e-module development studies, suggesting that the absence of appropriate materials is felt most acutely precisely where sensory barriers are greatest. The observed reliance on degraded printed posters is consistent with what Erianti et al. (2022) found in adaptive physical education practicum courses, where the lack of sequential visual guidance left students unable to reconstruct movement procedures independently. Internationally, the rapid diffusion of digital-intelligent technologies into physical education (Li et al., 2025) makes the continued analog condition of special school gyms increasingly anomalous. The implication is straightforward: developing visual multimedia for this population is not an incremental improvement but a correction of a fundamental design error in which instruction is encoded in a channel the learners cannot access. Practically, the needs-analysis procedure used here combining observation, interpreted interviews, and a dual-respondent questionnaire offers a replicable template for other special schools preparing similar development projects.

A further distinctive need emerged around rhythmic activities. Conventional rhythmic gymnastics in physical education depends on music and counted beats, both inaccessible to deaf students; teachers reported substituting shouted counts that only students with residual hearing could partially follow. The e-module's replacement of audio with visual markers color-coded beat indicators, animated trajectory lines, and vibrotactile tempo cues answers this barrier directly. This adaptation extends the logic of visual teaching strategies for deaf learners (Luckner et al., 2001) into a domain where sound had previously been treated as irreplaceable, and it illustrates a broader principle: in adaptive physical education, the constraint is rarely the activity itself but the sensory channel through which its structure is communicated.

2. Product Validity in Light of Multimedia Learning Theory and Universal Design

The convergent judgment of three experts with complementary specializations content, media, and special education places the e-module's feasibility (92.53%) in the highest validity category. This convergence matters because the product sits at the intersection of three quality criteria that are often assessed separately: disciplinary correctness of the movement content, technical-pedagogical quality of the multimedia, and psychological appropriateness for deaf learners. The result compares favorably with recent development studies. Almaas et al. (2025) reported content and media validity coefficients of 0.94 for biology e-modules, with teacher and student practicality of 88.33% and 93.55% respectively figures remarkably close to the 88.75% and 91.00% practicality obtained here. Utami et al. (2023) achieved very good content and good media ratings for their e-module for students with hearing impairment, while Badiah and Kurniawan (2025) obtained very effective ratings without revision for their universal-design module. The present product matches these benchmarks while covering a more demanding content domain, since psychomotor material must be communicated without any auditory channel.

Theoretically, the validation outcome supports two propositions. First, the coherence, signaling, and segmenting principles of the cognitive theory of multimedia learning (Mayer, 2021) transfer effectively to deaf learners when the modality principle is inverted: rather than shifting verbal information from text to narration, narration is eliminated and the visual channel is enriched with sign language interpretation, dynamic highlighting, and slow-motion segmentation. Second, the expert revisions three-level movement variations, haptic tempo feedback, adjustable typography demonstrate that Universal Design for Learning guidelines (CAST, 2018) can be operationalized concretely in a psychomotor digital product, not merely invoked rhetorically. The alignment of the product with established module-development frameworks (Calamlam, 2021; Natarajan & Charles, 2024) further indicates that the development process, not only the product, met contemporary quality standards.

The validation results also position the product within the Indonesian e-module development trajectory. Recent reviews show that Indonesian e-module research has concentrated on mainstream academic subjects (Almaas et al., 2025), with products such as metacognition-based biology e-modules (Haka et al., 2021) and interactive digital books for programming courses (Mahendri et al., 2023) achieving high validity without addressing learners with sensory disabilities. The present study demonstrates that the same development rigor systematic needs analysis, expert judgment, and iterative field trials can be transferred to special education contexts, provided that accessibility engineering is treated as a core design requirement rather than an afterthought. The three-level differentiation mechanism additionally answers calls in the differentiated instruction literature for e-modules that adapt to learner readiness rather than merely digitizing uniform content (Liu et al., 2024).

3. Effectiveness of the E-Module on Movement Understanding

The large-group trial produced a significant and practically substantial improvement in movement understanding: a mean gain of 26.30 points, $t(51) = 27.641$, $p < 0.001$, with an effect size of 3.37. Three mutually reinforcing mechanisms plausibly account for this outcome. First, the dual visual coding of movement demonstration video plus step-by-step animation plus concise text allowed students to construct stable mental representations of motor sequences without depending on translation of spoken language, exactly the compensation predicted when the cognitive theory of multimedia learning is adapted to deaf learners (Mayer, 2021). Second, the three-level scaffolding let each student enter tasks within the zone of proximal development: guided imitation for beginners, icon-based following for intermediate learners, and independent exploration for advanced students (Vygotsky, 1978). Notably, students with the lowest pretest scores (38–48) achieved normalized gains above 0.60, indicating that the scaffolding operated most powerfully where the need was greatest. Third, user-controlled pacing replay, pause, frame-by-frame navigation externalized the segmenting principle, transferring control of cognitive load from the teacher to the learner.

These findings align with and extend prior evidence. Video-based applications with sign support improved physical education comprehension and academic self-concept among hearing-impaired students (Andriyani et al., 2021); video tutorial delivery significantly enhanced content comprehension of deaf and hard-of-hearing students when image and text were combined (Al-Fannah et al., 2022); and audiovisual materials adapted to individual needs improved knowledge acquisition among students with hearing loss (Akay, 2021). The present study adds two elements absent from that work: a constructivist learning sequence rather than mere media exposure, and effectiveness evidence measured through pre-post testing rather than perception alone. The constructivist contribution also resonates with Abiatal and Howard (2020), who found that constructivism-led assistive technology raised achievement and self-regulation among deaf learners, and with Petrov et al. (2025), who showed that technology-enhanced adaptive physical education improves motor indicators in other disability populations.

The moderate N-Gain of 0.552 deserves explicit interpretation rather than apology. In Hake's (1998) original formulation, moderate normalized gains characterize instruction that produces genuine conceptual change without fully displacing prior conceptions expected profile when the target competence is psychomotor understanding consolidated through physical practice over time. Four weeks of twice-weekly meetings is sufficient to reorganize cognitive representation of movement but not to automate it. The very large effect size alongside a moderate normalized gain reflects the heterogeneity of initial ability: low scorers gained dramatically (N-Gain > 0.60), while students already near the ceiling could not gain proportionally. The practical implication is that the e-module functions best as a cognitive-stage scaffold preceding and accompanying physical practice, not as a substitute for it a division of labor consistent with how differentiated e-modules operate in mainstream settings (Liu et al., 2024).

4. Constructivist Mechanisms behind Motivation and Engagement Gains

The 34.72% rise in learning motivation and the jump in engagement from 58.30% to 87.50% are best explained through self-determination theory. The e-module systematically supported the three basic psychological needs: autonomy, through self-paced navigation and free choice of difficulty level; competence, through immediate visual feedback and graduated scaffolding that made success attainable at every level; and relatedness, through paired practice and visual peer feedback (Ryan & Deci, 2000). Constructivist learning environments are theorized to sustain precisely these motivational conditions (Jonassen, 1999), and special education research confirms that constructivist assistive technology strengthens self-regulation and metacognitive awareness in deaf learners (Abiatal & Howard, 2020; Özer Şanal & Erdem, 2023). Comparable motivational effects of structured digital modules have been reported for self-regulated learning designs (Ganendra et al., 2025) and for digital-intelligent physical education environments (Li et al., 2025). Most directly, virtual-reality coaching in physical education significantly raised motivation and participation among students with learning disabilities (Mokmin & Rassy, 2025), paralleling the motivational gains observed here for deaf learners.

The engagement profile sharpens this explanation. Engagement peaked during demonstration-video viewing (94.20%) and interactive quizzes (91.30%) the two features that most directly embody behavioral, emotional, and cognitive engagement as conceptualized by Fredricks et al. (2004). Behavioral engagement appeared as active participation and spontaneous practice; emotional engagement as visible enthusiasm and requests to replay content; cognitive engagement as persistent attempts at harder movement variations. This pattern is consistent with the documented visual-kinesthetic preference of deaf and hard-of-hearing learners (Podkamennyy et al., 2025) and with evidence that immersive visual technologies deepen involvement and retention (Berrezueta-Guzman et al., 2025). It also extends Rehman et al. (2024), who linked technology integration to improved collaboration among students with hearing impairment: in this study, collaboration emerged spontaneously around the shared visual reference the e-module provided. Understanding, motivation, and engagement thus appear to have formed a positive feedback loop clearer movement representations made practice feel attainable, success fed motivation, and motivated practice deepened engagement.

An embodied cognition reading completes the explanation. For deaf students, understanding a movement is inseparable from feeling it; the e-module's observation–imitation–exploration cycle mirrors the natural epistemology of motor learning, in which visual perception guides physical trial and proprioceptive feedback refines the next attempt. The constructivist sequence did not ask students to learn about movement and then to move; it asked them to construct movement knowledge through repeated cycles of seeing, doing, and reflecting. This design choice explains why engagement remained highest precisely at the moments of greatest cognitive demand watching demonstrations and solving quizzes rather than collapsing when tasks became difficult. Where conventional instruction produced passive waiting, the e-module converted waiting time into self-directed replay and rehearsal, turning the visual channel from a compensatory workaround into the primary engine of learning.

Positioned against the closest prior work, the contribution of this study becomes precise. Relative to Andriyani et al. (2021), the e-module adds an explicit constructivist instructional architecture and three-level motor differentiation. Relative to Utami et al. (2023), it moves accessibility-driven e-module design from academic content into the psychomotor domain of adaptive physical education. Relative to Badiah and Kurniawan (2025), it addresses hearing rather than visual impairment and school-age rather than university learners. Relative to Abiatal and Howard (2020), it demonstrates constructivist assistive technology in movement-based rather than classroom-academic learning. The theoretical contribution is correspondingly threefold: it shows that the modality and redundancy principles of multimedia learning must be re-specified, not merely applied, for learners without an auditory channel; it operationalizes the constructivist learning environment concept in the psychomotor domain through embodied observation-imitation-exploration cycles; and it provides an Indonesian special school validation of Universal Design for Learning in adaptive physical education. The practical contribution is a validated, ready-to-use product accompanied by a teacher guide, together with empirically observed minimum conditions for replication: five to ten tablets per class, initial internet connectivity for installation, two to three hours of teacher briefing, adequate movement space, and basic technical support. Sustained use, however, will depend on structured teacher professional development, which recent meta-analytic evidence identifies as the strongest lever for lasting instructional change in physical and special education contexts (Hutzler et al., 2024; Kalynychenko et al., 2021; Sims et al., 2025). Where device availability is limited, the station-rotation format observed at one school small groups alternating between tablet stations and physical practice stations proved workable despite slower loading.

Several limitations qualify these conclusions. The one-group pretest-posttest design cannot fully exclude history, maturation, and testing effects, so causal attribution should be read as strong but not definitive. The sample of 52 students came from four schools in one metropolitan area, and the four-week intervention cannot speak to long-term retention. The measured outcomes were movement understanding, motivation, and engagement; actual motor skill performance was assessed only formatively. Expert validation involved three validators, and the researcher-provided devices during the trial may not reflect the infrastructure available in ordinary special schools. These limitations define the agenda for the follow-up studies recommended below.

D. Conclusion

This study developed a multimedia-based adaptive physical education e-module grounded in a constructivist approach for deaf students in special schools and tested it through a complete 4D development cycle. Four conclusions follow. First, the needs of deaf students and physical education teachers in Medan special schools were very high: instruction was verbal and teacher-centered, no adaptive digital media existed, and all respondents demanded visual multimedia materials. Second, the e-module proved very valid, with expert feasibility ratings averaging 92.53% across content, media, and special education judgments, and very practical, with small-group ratings of 91.00% from students and 88.75% from teachers. Third, the e-module was effective: understanding of adaptive movement rose from 52.35 to 78.65, with a significant paired difference ($t(51) = 27.641$, $p < 0.001$), a moderate normalized gain of 0.552, and a large effect size of 3.37; learning motivation increased by 34.72% and student engagement from 58.30% to 87.50%. Fourth, the product's distinctive contribution lies in being the first validated integration of sign-language-embedded multimedia, three-level constructivist scaffolding, and comprehensive adaptive physical education content for deaf learners.

Scientifically, the study extends the cognitive theory of multimedia learning to psychomotor learning for students without auditory access and demonstrates that constructivist learning environments can be embodied in movement-based digital products. Practically, it supplies special schools with a ready-to-use e-module and teacher guide whose minimum implementation conditions are now known. Teachers are advised to combine the e-module with direct physical practice and, where devices are scarce, to apply station rotation. Future research should employ quasi-experimental designs with control groups, examine longitudinal retention, replicate the product across regions and grade levels, integrate artificial-intelligence-based movement recognition and live sign language interpretation, and extend development to other disability categories.

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F. Conflict of Interest

The authors declare no conflict of interest regarding the publication of this article.

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