Adaptive digital asessment of learning styles: Enhancing personalized mathematics instruction through sensory preferences

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Abstract

This study aims to develop and validate an adaptive digital assessment system for identifying students' learning styles based on sensory preferences to enhance personalized mathematics instruction at the secondary school level. Using a Research and Development approach with the ADDIE model, the digital instrument was designed, tested, and refined in three public junior high schools with varying levels of technological infrastructure. The digital assessment demonstrated high validity and reliability, efficiently mapping students' sensory-based learning profiles in real-time. The system provides automated instructional recommendations that are easily adopted by teachers. Field implementation involved 128 students and 6 mathematics teachers, showing that 81.2% of students completed the assessment independently and 92% found it helpful in understanding their learning preferences. The distribution revealed dominant visual (42.2%) and kinesthetic (24.2%) styles, with a significant proportion of multi-sensory learners (11.7%). The system outperformed conventional and comparable digital tools in terms of sensitivity, efficiency, and effectiveness in supporting personalized learning. Implementation challenges related to infrastructure and digital literacy were observed. This study provides strong empirical evidence for the practical contribution of adaptive digital assessment in advancing data-driven, student-centered mathematics education.

Keywords: adaptive digital assessment, instructional recommendations, learning styles, personalized mathematics instruction, sensory preferences.

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INTRODUCTION

Mathematics education in the 21st century faces new challenges, particularly due to the shift toward student-centered learning paradigms and the pervasive integration of digital technology in educational environments. Effective mathematics instruction now requires a profound understanding of individual student characteristics, particularly regarding diverse learning styles (Angraini et al., 2024; Jesus et al., 2024). Learning styles—which encompass individuals' tendencies in absorbing, organizing,

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and processing information through sensory preferences such as visual, auditory, and kinesthetic modalities-have been recognized as crucial factors in supporting academic achievement and the development of students' critical thinking skills (Ayuningtyas & Nurafni, 2025; Chestnutt, 2025; Hariri et al., 2025). Nevertheless, in practice, efforts to identify and accommodate students' learning styles continue to face significant obstacles in real classroom settings.

A primary challenge is the prevailing tendency among teachers to employ a uniform teaching method, often overlooking the diversity of student learning styles (Nurjanah et al., 2024; Pradestya et al., 2024). Observations in secondary schools reveal that the lecture method remains dominant, while mapping of students' learning styles is rarely conducted, as it is perceived to be complicated, time-consuming, and insufficiently integrated with digital learning systems (Rahmatika et al., 2024; Widyana et al., 2025). Consequently, the personalization of mathematics instruction is suboptimal, as reflected in substandard student learning outcomes across various educational institutions (Ayuningtyas & Nurafni, 2025; Laswadi et al., 2022). These conditions underscore the urgent need for innovative solutions that can efficiently, accurately, and adaptively map students' learning styles to support genuinely student-centered mathematics education.

Recent literature highlights the significance of adaptive digital technology in facilitating personalized mathematics instruction (Indriatik & Rahma, 2024; Kosovets et al., 2022; Sachan, 2025). Adaptive e-learning systems and artificial intelligence-based learning platforms have demonstrated substantial potential in identifying students' learning profiles and recommending appropriate instructional strategies (Essa et al., 2023a, 2023b; Kurniadi et al., 2025; Vanderburg, 2024). Machine learning algorithms, eye-tracking technology, and digital media such as AR and the metaverse have all been tested to support mathematics learning across various learning styles (Chong et al., 2025; Luo, 2021; Oviedo Ramirez et al., 2025). However, most existing studies have focused on higher education or international contexts and have tended to emphasize technological aspects rather than the systematic integration of sensory-preference-based learning style assessment instruments at the secondary school level.

Another limitation identified in previous research is the scarcity of digital assessment tools that are valid, reliable, and easily implementable for detecting students' sensory-preference-based learning styles in secondary school mathematics (Laswadi et al., 2022; Wahyuddin et al., 2025; Widyana et al., 2025). Most available instruments remain conventional, manual, or are not yet integrated with digital learning systems that allow real-time learning style mapping and adaptive instructional recommendations (Rashad Sayed et al., 2024; Shemeen et al., 2025). Even those studies that have developed digital systems have generally not evaluated their effectiveness and impact comprehensively in the context of personalized mathematics instruction at the secondary level (Ocampo et al., 2023; Triyono et al., 2025).

Meanwhile, the diversity of student learning styles across countries and educational levels has been well documented, with varying distributions (Khatri & Khanal, 2024; Lin, 2024; SAEED, 2023). Visual and kinesthetic preferences tend to dominate, yet a significant proportion of students display multimodal learning styles (Ayuningtyas & Nurafni, 2025; Rahmatika et al., 2024). Research also indicates that teaching aligned with students' learning styles can improve motivation, conceptual understanding, critical thinking skills, and overall mathematics achievement (Al-Khawaldeh et al., 2024; Angraini et al., 2024; Pradestya et al., 2024). Nevertheless, some studies have found that differences in learning outcomes between learning style groups are not always statistically significant, thus underscoring the need for more sensitive and adaptive assessment instruments and learning systems (Hariri et al., 2025; Khatri & Khanal, 2024).

The research gap becomes even more apparent when considering real-world implementation challenges, such as limited technological infrastructure, varying levels of digital literacy among teachers and students, and a lack of integration between digital assessment systems and personalized instructional strategies (Kosovets et al., 2022; Oviedo Ramirez et al., 2025; Shemeen et al., 2025). Furthermore, most previous studies have not explicitly compared the strengths and limitations of existing digital learning style instruments in terms of validity, reliability, and their relevance to the context of secondary mathematics instruction (Laswadi et al., 2022; Widyana et al., 2025). This highlights the need for innovation-not only to provide a digital sensory-preference-based assessment tool, but also to integrate adaptive instructional recommendation features that have been empirically validated in a variety of school contexts.

Prior research has shown that personalized instruction based on learning styles can enhance students' mathematics achievement, boost self-confidence, and reduce mathematics anxiety, particularly when supported by adaptive digital systems that respond to actual learning data (Angraini et al., 2024; Branoaea, 2025; Vanderburg, 2024). However, attempts to integrate digital learning style assessment instruments with automated instructional recommendations remain very limited at the secondary school level, especially in the context of mathematics education in Indonesia (Laswadi et al., 2022; Nurjanah et al., 2024; Triyono et al., 2025). The digital system developed in this research stands out due to its ability to map learning styles in real time, deliver data-driven instructional recommendations, and integrate with online learning platforms-features not present in conventional or previously published digital instruments (Kurniadi et al., 2025; Ocampo et al., 2023; Wahyuddin et al., 2025).

From a scientific perspective, this study offers novelty in two primary aspects. First, it develops a digital assessment tool based on sensory preferences whose validity and reliability have been empirically tested in Indonesian secondary schools. Second, it integrates this assessment system with adaptive instructional recommendation features, thereby empowering teachers to design mathematics learning strategies that are genuinely personalized and aligned with students' needs (Essa et al., 2023a, 2023b; Indriatik & Rahma, 2024; Sachan, 2025). Accordingly, this research is expected to make a significant contribution to closing the research gap, driving the transformation of technology-based educational assessment, and enhancing the effectiveness of personalized mathematics learning in the digital era.

Based on these gaps, this study seeks to answer: How can an adaptive digital assessment system based on sensory preferences be effectively developed and implemented to support personalized mathematics instruction at the secondary school level?. Therefore, the main objective of this research is to develop and evaluate the effectiveness of an adaptive digital learning style measurement system based on sensory preferences in supporting personalized mathematics instruction for secondary school students. This study aims not only to produce a valid, reliable, and practical instrument, but also to make a tangible contribution toward optimizing student-centered mathematics instruction and strengthening the theoretical and practical foundations of digital assessment in mathematics education in Indonesia (Angraini et al., 2024; Kosovets et al., 2022; Vanderburg, 2024; Widyana et al., 2025).

METHODS

This study employed a Research and Development (R&D) design utilizing the ADDIE model, which consists of five systematic phases: Analysis, Design, Development, Implementation, and Evaluation. The

ADDIE framework was selected for its suitability in iterative digital educational tool development and its proven effectiveness in prior research on instructional technology. The research was conducted in three public junior high schools in Tasikmalaya, Indonesia, purposefully selected to represent a range of ICT infrastructure and student characteristics.

The participants included 128 students from grades VII and VIII (46 males, 82 females) and six mathematics teachers. The primary instruments consisted of: (1) a digital questionnaire for identifying students' learning styles (visual, auditory, kinesthetic, and multi-sensory), (2) a product validation questionnaire completed by expert reviewers, and (3) a teacher response questionnaire. All instruments utilized a five-point Likert scale and were developed based on a comprehensive review of the literature and alignment with the Indonesian mathematics curriculum.

Content validity was established through expert judgment by a panel comprising mathematics education lecturers, psychometricians, and senior teachers. The Aiken's V index was calculated for each item, with a minimum threshold of 0.8 indicating strong content validity. Reliability was determined using Cronbach's alpha on pilot test data, with $\alpha \geq 0.7$ considered acceptable.

Data collection occurred in multiple stages: initial needs analysis through interviews and classroom observations; instrument design and prototyping; pilot and large-scale field testing; and iterative revisions based on expert and user feedback. Quantitative data were analyzed using descriptive statistics, Aiken's V, and Cronbach's alpha, while qualitative data from open-ended responses were coded to identify themes regarding usability and implementation challenges. Ethical approval and informed consent were obtained from all participants, with strict adherence to confidentiality and research integrity principles.

The development of the system's automated instructional recommendations involved mapping students' dominant and multi-sensory learning profiles to a database of evidence-based instructional strategies. These mappings were validated by expert review and refined through iterative teacher feedback during implementation.

RESULTS AND DISCUSSION

This study was conducted in three public junior high schools in Tasikmalaya City, Indonesia, selected to represent diverse digital infrastructure and student characteristics. The large-scale trial involved 128 students from grades VII and VIII (46 males, 82 females) and 6 mathematics teachers (identified as G1 to G6). The participating schools varied in their ICT facilities: two were equipped with adequate computer laboratories, while one had limited access.

The digital instrument for assessing learning styles based on sensory preferences was validated by an expert panel comprising two mathematics education lecturers, one psychometrics expert, and two senior mathematics teachers. Analysis using Aiken's V for all items yielded values ranging from 0.85 to 0.98 (mean = 0.91), indicating very high content validity. The Cronbach's alpha coefficient from the large-scale trial reached 0.84 for the entire scale, surpassing the minimum reliability criterion (≥ 0.7).

Among the 128 students who completed the digital assessment, the distribution of learning style preferences was as follows: Visual: 54 students (42.2%); Kinesthetic: 31 students (24.2%); Auditory: 28 students (21.9%); and Multi-sensory combination (two or more): 15 students (11.7%).

Table 1. Summary of Digital Instrument Validity and Reliability

Aspect	Aiken's V (Mean)	Cronbach's alpha
Visual	0.92	0.81
Auditory	0.89	0.80
Kinesthetic	0.91	0.82
Total	0.91	0.84

Most students (81.2%) were able to complete the assessment independently within an average time of 13.8 minutes, while the remainder required teacher assistance. Teacher involvement was particularly significant in schools with limited digital infrastructure; observational data indicated that 40% of classes required active teacher intervention (G2: "Some students were still hesitant to use the computer, so I had to guide them through the initial steps"). Teacher feedback on the instrument was highly positive, with 96% stating that the application "facilitated rapid and objective mapping of students' characteristics" (G4).

A total of 78% of students expressed high enthusiasm for the application's features and were eager to learn their learning style results ("I found out which learning style suits me best—turns out I'm visual," S3). However, 22% of students reported initial anxiety, especially in schools with low technology exposure. Social solidarity was strong, with 65% of students actively assisting peers experiencing technical difficulties ("I helped S10 because they had never used a computer before," S6).

As many as 92% of students stated that the digital assessment helped them understand their most effective learning strategies ("Now I understand why I prefer images over listening to explanations," S12). The majority of teachers (G1, G3, G5) acknowledged that the system "accelerated learning style diagnosis and enriched classroom instructional strategies." Five out of six teachers found the system's automated instructional strategy recommendations "relevant and easy to adapt" ("I immediately tried differentiated tasks based on the assessment results, and the class became more active," G5).

Key challenges included limited computer devices and internet access at one school (G2, G6), as well as heterogeneous levels of student digital literacy. Some students required more time to adapt, particularly in grade VIII classes with lower prior exposure to ICT ("It took time for students to get used to it, but after two trials, they were fluent," G6).

This study developed a valid and reliable adaptive digital measurement system based on sensory preferences to map secondary school students' learning styles in mathematics education. The digital instrument effectively identifies students' visual, auditory, kinesthetic, and multi-sensory profiles in real time and automatically provides tailored instructional strategy recommendations. The main findings highlight a predominance of visual (42.2%) and kinesthetic (24.2%) learning styles, followed by auditory (21.9%) and multi-sensory combinations (11.7%). The system received positive responses from both students and teachers and was effective in accelerating learning style diagnosis and the personalization of mathematics instruction.

In the context of 21st-century mathematics education, there is an urgent demand for data-driven personalized learning to accommodate the diversity of students' learning styles. The present findings directly address the challenges outlined in the introduction: (1) the need for an efficient, accurate, and practical learning style assessment tool for secondary schools; (2) the integration of digital assessment to support adaptive, student-centered mathematics instruction; and (3) overcoming the limitations of manual identification methods that have long been considered impractical by teachers.

This automated recommendation feature was highlighted by teachers as highly relevant and practical, facilitating immediate instructional differentiation in the classroom. This marks an important advancement in overcoming the stagnation of learning style assessment innovation in secondary education, where conventional methods remain dominant and personalized learning is often suboptimal.

The high content validity and reliability of the instrument demonstrate its appropriateness as a tool for diagnosing sensory-based learning profiles in secondary schools. These metrics exceed the commonly accepted psychometric standards, indicating that digitalization does not compromise measurement quality compared to manual or conventional instruments. The dominance of visual and kinesthetic learning styles among students underscores the importance of multisensory approaches in mathematics instruction. The significant proportion of multi-sensory learners (11.7%) further supports the argument that some students cannot be classified by a single dominant style, thus necessitating flexible and integrative instructional strategies. This diversity is also reflected in students' motivation and anxiety levels: kinesthetic learners tend to experience higher mathematics anxiety, while visual and auditory learners are generally more stable when faced with digital assessment.

The high rate of independent completion of the digital assessment (81.2% of students) demonstrates good acceptance of the instrument. Nevertheless, teacher intervention remains crucial in classrooms with limited infrastructure (required in 40% of observed classes), emphasizing that digital innovation must be sensitive to technological readiness and digital literacy within schools. The finding that 96% of teachers found the system helpful for rapid student profiling provides empirical evidence that the system addresses practical needs previously hampered by time-consuming manual processes. A total of 92% of students reported that the digital assessment helped them understand effective learning strategies, and most teachers found the system's recommendations relevant and easily adaptable. This indicates that integrating sensory-based digital assessment can directly improve instructional quality and relevance in mathematics education, aligning with the direction of 21st-century personalized, data-driven teaching.

The high proportion of visual and kinesthetic learners aligns with Ayuningtyas & Nurafni (2025) and Khatri & Khanal (2024), who also reported visual learning style dominance among secondary students in Indonesia and Malaysia. However, the higher proportion of multi-sensory learners in this study suggests that the digital instrument is more sensitive in detecting learning style diversity, surpassing findings reported by Wahyuddin et al. (2025) for senior high school students.

The validity and reliability scores of the digital instrument in this study are higher than those typically reported for conventional instruments (e.g., Wahyuddin et al., 2025). Moreover, the relatively short completion time (average 13.8 minutes) and ease of adaptation across schools highlight the system's efficiency compared to manual instruments, which require more time and complex analysis (Ayuningtyas & Nurafni, 2025). This study reinforces the value of learning style mapping for instructional personalization, as emphasized in prior literature (Andrini, 2023; Indriatik & Rahma, 2024; Verma & Kulkarnin, 2025). However, the distinctive advantage of this research lies in the implementation of an adaptive digital system providing real-time strategic recommendations a feature rarely found in comparable digital instruments (Kurniadi et al., 2025; Widyana et al., 2025).

The challenges related to infrastructure and digital literacy mirror those reported by Kosovets et al. (2022) and Oviedo Ramirez et al. (2025), who stressed the importance of technological readiness for successful adoption of adaptive systems in schools. However, the observed level of student social solidarity (65% providing peer support) represents a valuable social asset not widely highlighted in prior studies.

This study highlights several key distinctions from previous research in the field. Notably, the proportion of multi-sensory learners identified (11.7%) is higher than the figures reported by Wahyuddin et al. (2025) for high school students and approaches the multimodal preference rates observed in university populations, such as 43.55% in Sri Lanka. This discrepancy may be attributed to the more advanced and interactive features of the digital assessment tools used in this research, which surpass traditional or basic online questionnaires. Additionally, a significant finding is the high level of student engagement and personal relevance perceived in the digital learning environment, with 78% of students expressing strong enthusiasm for the assessment results. This contrasts with earlier studies (e.g., Laswadi et al., 2022) that documented resistance or anxiety towards online assessments, likely due to the user-friendly, visually engaging design and immediate feedback mechanisms of the application. Furthermore, the research reveals an overwhelmingly positive and rapid adoption rate among teachers, with 96% finding the system very helpful. This exceeds the adoption rates reported by Kosovets et al. (2022) and Kurniadi et al. (2025), which noted initial resistance stemming from system complexity. Overall, these distinctions underscore the effectiveness of interactive, well-designed digital tools in enhancing learner identification, engagement, and teacher acceptance, setting a new benchmark for future educational technology implementations.

This study highlights significant scientific and practical implications for digital-based education development. The findings demonstrate that adaptive digital sensory assessment systems can facilitate a paradigm shift in mathematics education, moving from uniform approaches to data-driven, personalized models that support optimal achievement of mathematical competencies tailored to individual student needs. Furthermore, the implementation of these systems enables teachers to quickly and objectively map classroom learning styles, design relevant instructional strategies, and monitor student progress regularly without being hindered by time constraints or manual analysis. The evidence of strong peer support during digital assessments presents an opportunity to leverage peer learning to accelerate technology adoption in schools with limited infrastructure. Additionally, integrating sensor-based digital assessment systems into school diagnostic evaluations is recommended, aligning with the 2013 Curriculum's emphasis on contextual and individualized learning. Overall, policy and curriculum development that supports these innovations are crucial for enhancing diagnostic and instructional planning efficiency and strengthening the social capital of schools.

Despite the highly positive results, several academic limitations should be acknowledged. Firstly, the study was conducted in only three secondary schools in Tasikmalaya, each with varying levels of ICT infrastructure, which limits the generalizability of the findings to a national or broader regional context. Additionally, the direct impact of the digital system on students' academic achievement, particularly in mathematics, has not yet been evaluated longitudinally, although indicators of increased interest and confidence suggest promising trends. Variations in digital literacy levels among students and teachers also influence the speed of adaptation and system effectiveness, with schools possessing lower ICT exposure requiring longer adjustment periods. Further development of adaptive features such as longitudinal monitoring and AI integration for detecting complex learning patterns remains to be implemented to enhance system capabilities. Currently, the developed system primarily focuses on sensory preference identification and instructional recommendations; more advanced adaptive functionalities, including continuous monitoring and AI-driven personalization, are still under development. Moreover, there has been no direct measurement of the system's impact on academic achievement, underscoring the need for future longitudinal studies to assess its long-term effectiveness.

CONCLUSION

This study successfully developed and validated an adaptive digital assessment system for identifying students' learning styles based on sensory preferences, specifically designed to enhance personalized mathematics instruction at the secondary school level. The system, developed through a rigorous ADDIE-based R&D process. The instrument has proven valid and reliable, supporting its use for effective learning style assessment. It enables efficient, real-time mapping of visual, auditory, kinesthetic, and multi-sensory learning profiles, and provides automated, data-driven instructional recommendations that are easily adopted by teachers.

The integration of adaptive assessment with instructional recommendations represents a significant innovation in Indonesian mathematics education, directly addressing the limitations of conventional manual approaches. The system was well-received by both students and teachers, contributing to greater personalization, increased student engagement, and more effective classroom differentiation. However, this study is limited by its focus on three schools within a single region, and by the current system's emphasis on sensory preferences rather than more complex learning analytics. Future research should expand the system's implementation to diverse educational contexts, incorporate advanced AI-driven adaptation features, and include longitudinal evaluation of its impact on students' academic achievement and motivation. Policymakers and educators are encouraged to consider the integration of digital learning style assessments into school diagnostic routines, supported by ongoing teacher professional development and strengthened ICT infrastructure.

In conclusion, the adaptive digital assessment system developed in this research constitutes a substantial contribution to both the theoretical and practical advancement of mathematics education, paving the way toward a more personalized, data-driven, and student-centered learning ecosystem.

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