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Visual and Auditory Learning Styles in Mathematics Learning in the Digital Era for College Students

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ABSTRACT

In the digital era, higher education mathematics faces challenges in aligning complex material with diverse student learning styles. The mismatch between traditional teaching methods and students' sensory preferences often hinders the understanding of abstract concepts within dominant digital platforms. This study aims to analyze and describe the tendencies of visual and auditory learning styles among mathematics education students at Muhammadiyah University of Makassar within digital learning contexts. Employing a qualitative descriptive approach, data were gathered through a Visual-Auditory-Kinaesthetic (VAK) questionnaire, observations of digital learning activities, and in-depth interviews. The data analysis process—comprising data reduction, data presentation, and conclusion drawing—mapped how these learning styles influence student interaction with digital media. The results revealed that students' learning styles are dominated by visual (55%) and auditory (35%) tendencies. Visual learners excelled in interacting with dynamic mathematical software simulations and structured instructional videos, while auditory learners processed concepts more effectively through synchronous discussions on video conferencing platforms and educational podcasts to construct procedural logic. Furthermore, the findings indicate a significant behavioral shift toward multimodal adaptability, where students independently leverage technological features to overcome the limitations of unipolar material. Theoretically, this research contributes to developing adaptive mathematics pedagogical strategies in higher education. Practically, these insights recommend the implementation of Differentiated Learning strategies and a Universal Design for Learning (UDL)-based curriculum that integrates interactive visual elements and clear auditory narratives to minimize cognitive barriers, thereby optimizing students' mathematical literacy.

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1. INTRODUCTION

Mathematics is often viewed as the "Queen of Sciences," underlying the development of modern technology (Prasanna, 2022). However, despite its vital role, mathematics remains a subject considered rigid, abstract, and difficult to grasp by most higher education students (Schoenfeld, 2022). Entering the digital era, this challenge has undergone a transformation. Today's students, often categorized as digital natives, interact with information very differently than previous generations (Alenezi et al., 2023; Viktor et al., 2019). Information is no longer linear, but rather hypertextual, multimedia, and instantaneous.

In higher education, particularly in the Mathematics Education Study Program at Muhammadiyah University of Makassar, the demand to master complex mathematical concepts such as real analysis, abstract algebra, or mathematical modelling now confronts digital distractions and changing cognitive patterns. The primary issue is not a lack of resources, but rather how these abundant digital resources can be effectively absorbed by students with varying sensory preferences. The unpreparedness of institutions or lecturers to map student learning styles amidst the flood of digital information can lead to failure to achieve graduate learning outcomes.

Theoretically, a learning style is a consistent way an individual perceives stimuli or information, remembers, thinks, and solves problems (Costa et al., 2020; Rahawarin et al., 2026; Syahri, 2025). In the context of mathematics, the two most dominant sensory domains are visual and auditory learning styles (Abu Mansor & Abu Mansor, 2025). Visually inclined students rely heavily on graphical representations, diagrams, and spatial representations to understand mathematical structures (Kus & Newcombe, 2025). In contrast, auditory learners rely on the power of hearing, discussion, and verbal explanations to construct mathematical logic in their minds (Harefa et al., 2026).

The digital era presents a paradox for these two learning styles. On the one hand, technology offers sophisticated visualization tools like GeoGebra, Desmos, or AR/VR simulations that are supposed to cater to visual learners (Montejo et al., 2026). On the other hand, audio-based content like educational podcasts, YouTube video tutorials, and AI voice command features provide new opportunities for auditory learners. However, the reality on the ground shows that many students still experience a "cognitive deadlock". This occurs because the digital media they use is often not designed with a balance of learning styles in mind, or because students themselves are unaware of the digital learning strategies most relevant to their sensory personality type (Kanchon et al., 2024; Nurmalisa et al., 2023).

Digital transformation in higher education is no longer just an option but a necessity. The use of learning management systems (LMS), collaborative platforms, and the use of artificial intelligence (AI) have transformed the landscape of the mathematics classroom (Alotaibi, 2024; Awang et al., 2025). For mathematics education students, this understanding is twofold: they must understand the mathematics content as learners, and at the same time, they must learn how to teach it again in the future using digital tools.

A frequent problem at Muhammadiyah University of Makassar is the gap between the availability of digital infrastructure and the effectiveness of material absorption. Students often fall into the trap of superficial technology use. For example, the use of text-heavy presentation slides may hinder visual learners who require mind mapping, while low-quality lecture recordings will hinder auditory learners from grasping the essence of the lecturer's logic. Therefore, research examining how these learning styles operate under the pressures of a digital environment is urgent.

Mathematics Education students at Muhammadiyah University of Makassar have unique characteristics influenced by their social environment and the demands of a curriculum based on progressive values. As future educators, they are required to possess high digital literacy. However, initial observations indicate that many students still struggle to make the transition from conventional to digital learning. The inability to identify their individual learning styles leads to inefficient learning strategies—for example, visual learners who try to learn solely by listening to verbal explanations without graphical scribbles, or auditory learners who are forced to read lengthy digital texts without any room for discussion.

This problem is exacerbated by the assumption that all digital materials are automatically suitable for everyone (Behrendt et al., 2026; Nurmalisa et al., 2023). However, the cognitive load in digital mathematics learning is very high. If digital input is not aligned with students' learning styles, information will simply pass through without becoming deeply understood (Gkintoni et al., 2025; Skulmowski & Xu, 2022; Xiang et al., 2025).

This research offers a novel approach by shifting the visual-auditory learning paradigm from conventional settings to the dynamic digital ecosystem of higher education in the era of the Industrial Revolution 4.0 and Society 5.0. This novelty lies in exploring the interaction between modern technological features, such as recommendation algorithms and virtual environments, and the preferences of mathematics education students at Muhammadiyah University of Makassar, who have their own unique sociocultural and technological adaptations. Unlike previous studies that tend to isolate sensory preferences (Gangadharan et al., 2025), this research examines the convergence of multimodal learning styles in digital media while uncovering aspects of student resistance to certain technologies (Selwyn, 2016), providing a critical perspective that goes beyond the technological optimism common in mathematics education literature.

The urgency of this research lies in the need for a comprehensive understanding of the mechanisms of mathematical material processing by students with visual and auditory learning styles in the digital era, in order to avoid inefficiencies in educational digitalization and waste of resources. By presenting in-depth empirical data, this research seeks to fill the gap in the literature and serve as a strategic compass for lecturers in implementing targeted differentiated learning. Thus, the results of this study are expected to guide educational practitioners at Muhammadiyah University of Makassar in designing curricula and learning media that are inclusive, adaptive, and based on students' cognitive characteristics, so that technology integration can become an effective bridge to more progressive mathematics mastery.

2. METHOD

This study employed a qualitative approach with a descriptive design to explore in-depth the visual and auditory learning styles of students. This approach was chosen because the researchers sought to understand the complex phenomenon of how mathematics education students interact with digital content through the lens of their learning styles. Using an interpretive paradigm, this study attempted to capture reality on the ground without intervention, thus obtaining an authentic picture of students' cognitive patterns in dealing with mathematics material in a digitalized higher education environment.

The subjects in this study were active students in the Mathematics Education Program at Muhammadiyah University of Makassar. Subject selection was conducted using a purposive sampling technique, with participants selected based on certain criteria: students who had taken core mathematics courses and had a high level of digital learning platform usage. The research location focused on the Muhammadiyah University of Makassar campus, which provides a unique context as an institution undergoing a massive digital transformation in its curriculum.

The primary instrument in this study was the researcher herself (human instrument), supported by a complementary instrument in the form of a validated VAK (Visual, Auditory, Kinesthetic) learning style questionnaire. The data collection process was conducted through triangulation techniques, including structured questionnaires, participant observation in a virtual classroom environment (LMS), and in-depth interviews. The interviews focused on students' subjective experiences absorbing mathematical information through digital media to uncover their most effective sensory preferences.

Given the focus of this research on the digital era, the observation method was developed through Digital Learning Observation. The researcher observed students' activities using mathematical software (such as GeoGebra or MATLAB) and how they interacted with video and audio-based materials. This observation aimed to validate the questionnaire data with actual student behavior in the digital world, for example, whether visual students tend to screenshot graphic visualizations or whether auditory students are more likely to replay the lecturer's oral explanations.

The collected data was analyzed using the interactive model of Miles, Huberman, and Saldaña, which consists of four stages: data condensation, data presentation, verification, and conclusion drawing. In the condensation stage, the researcher sorted relevant data based on visual and auditory characteristics and discarded information unrelated to the research focus. Next, the data was systematically organized in narrative form and matrix tables to facilitate the identification of learning style patterns that emerged in the context of digital mathematics learning at the university level.

To ensure the credibility and objectivity of the findings, this study implemented data validity testing through source triangulation and technical triangulation. The researcher

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compared interview data with questionnaire results and field observation notes. Furthermore, member checking was conducted by communicating preliminary findings back to the student participants to ensure that the researcher's interpretations aligned with their experiences. This step is crucial to avoid subjective bias in mapping student learning styles.

Research integrity is maintained through the application of strict ethical standards. Each participant was provided with an informed consent form explaining the purpose of the study and guaranteeing their anonymity. Furthermore, the use of artificial intelligence technology in the initial analysis and language processing of this manuscript was conducted transparently, in accordance with the latest scientific publication ethics policies. This was done to ensure that all research results are academically sound and make a tangible contribution to the development of mathematics pedagogy.

3. RESULTS AND DISCUSSION

Results

Analysis of Learning Style Distribution Based on Questionnaires (VAK)

Based on data collected through a learning style questionnaire on Mathematics Education students at the University of Muhammadiyah Makassar, varied but strong patterns were found in two main sensory domains. The data showed that 55% of students tended to have a visual learning style, while 35% were auditory learners, and the remaining 10% had a mixed or kinesthetic learning style.

Table 1. Percentage Distribution of Learning Styles of Mathematics Education Students

Learning Style	Percentage of Students	Dominant Key Characteristics
Visual	55%	Learn more effectively through visuals (pictures, diagrams, graphs, written text)
Auditory	35%	Learn more effectively through listening (lecturer explanations, discussions, audio recordings)
Mixed/Kinesthetic	10%	Learn more effectively through physical activity, hands-on practice, or a combination of several learning styles

Visual students scored high on indicators of their ability to remember information through images, diagrams, and graphical demonstrations in mathematical software. On the other hand, auditory students scored higher on their ability to process verbal instructions and group discussions. In this digital era, the questionnaire also revealed that visual students were more comfortable with materials in PDF format with rich color highlights, while auditory students preferred recorded lecturer explanations as their primary learning resource.

Results of Participatory Observation in a Digital Learning Environment

Observations were systematically conducted throughout the learning process across both synchronous video conferencing platforms and asynchronous Learning

Management Systems (LMS). The observational data revealed distinct behavioral patterns between the two primary learner types when interacting with digital interfaces. These behavioral tendencies demonstrate how students' underlying sensory preferences directly dictate their engagement and operational strategies when processing abstract mathematical concepts in a digital environment.

Students exhibiting a dominant visual learning style demonstrated highly active, hands-on engagement when interacting with dynamic visual tools. During simulations using the GeoGebra application, these individuals frequently manipulated visual parameters to observe real-time graphic transformations. Furthermore, their study habits leaned heavily toward visual preservation and organization; they consistently captured screenshots of critical presentation slides and utilized digital note-taking applications to synthesize the material into aesthetically structured, well-organized layouts.

Conversely, students with an auditory preference manifested entirely different engagement behaviors, prioritizing vocal communication and structural narrative over visual elements. During online discussion sessions, these students were notably vocal, frequently initiating questions and responding to the lecturer's verbal cues. When interacting with instructional videos, they often disengaged their gaze from the screen, choosing instead to focus intensely on the narrator's intonation and verbal emphasis. Additionally, they demonstrated a habit of frequently rewinding complex procedural explanations to clarify and reinforce the step-by-step logic of mathematical concepts. Data supporting these behavioral insights are systematically compiled in Table 2 below.

Table 2. Observation Results of Student Learning Behavior Based on Sensory Dominance

Learning Style Types	Behavior During Synchronous Learning (Video Conference)	Behavior During Asynchronous Learning (LMS / Digital Media)
Visual Learners	Very actively modifies visual parameters during simulations (GeoGebra application) to see graphical changes in real time. Frequently takes screen captures of important sections of lecturer presentation slides.	Organize digital notes aesthetically and neatly using a notes application.
Auditory Learners	Tends to be more vocal in asking questions or responding to verbal explanations during online discussion sessions.	When watching instructional videos, frequently look away from the screen but pay close attention to the narrator's intonation and emphasis. Frequently rewind sections of procedural explanations to understand the step-by-step logic.

In-Depth Interview Results: Reflections and Subjective Experiences

In-depth interviews were systematically conducted to investigate the underlying cognitive and psychological motivations driving students' distinct learning behaviors. By exploring these qualitative insights, the study successfully captured the nuanced academic experiences of both learner types in navigating abstract mathematics. The thematic analysis of the interview transcripts revealed contrasting perspectives on how digital learning environments either facilitate or hinder their conceptual understanding.

From the visual students' perspective, abstract mathematical domains—such as calculus and linear algebra—remain largely inaccessible without robust digital visualizations. Participants in this category emphasized that static text or abstract formulas often lead to cognitive overload and confusion. As one participant articulated, "I can only understand the concept of limits when I see a graph approaching a certain line on the screen; just reading text confuses me." These learners heavily relied on dynamic digital media, noting that features such as color-coded representations for different variables were critical in helping them map and differentiate complex mathematical structures.

Conversely, the auditory students expressed distinct challenges and preferences, revealing that the influx of text-heavy digital materials, such as standard e-books, constitutes a significant barrier to their learning. They reported a higher rate of comprehension when engaging in collaborative discussions, such as exchanging voice messages in WhatsApp groups, or when receiving direct verbal explanations from the instructor. This preference for acoustic guidance was highlighted by a student who stated, "For me, the lecturer's voice emphasizes which logic is most important in a theorem proof." For these learners, vocal inflection, tone, and auditory pacing serve as essential scaffolding for decoding rigorous mathematical logic.

Session 1: Visual Student Perspective

Interviewer	:	*Can you tell me about your experience so far when learning abstract math material, like calculus or algebra, using digital media?*
INF-01	:	*Personally, I find abstract math material like calculus or algebra impossible to understand without digital visualization. Honestly, if I'm just asked to read a long explanatory text, I get confused and get dizzy looking at the formulas.*
Interviewer	:	*Can you give a specific example of where visualization was most helpful?*
INF-01	:	*For example, when learning the concept of limits, I only really understood the concept of limits when I saw the graph moving toward a certain line on the screen. It gave me a concrete picture.*
Interviewer	:	*Besides graphs, is there anything else about digital media that makes it easier for you to understand mathematical variables?*
INF-01	:	*It's helpful when the media provides different color representations for each variable. The different colors make it easier for me to distinguish which components are changing and which are constant, so it's less confusing when the visuals shift.*

An informant with a predisposition for a visual learning style (INF-01) demonstrated a high reliance on pictorial and graphical representations in processing abstract mathematical material. For visual learners, lengthy explanatory texts and strings of conventional formulas without visual anchors trigger a high cognitive load (cognitive overload), which the informant described as confusing and overwhelming. This confirms that in the digital age, presenting calculus or linear algebra material in static text form is no longer adequate to meet the cognitive needs of students with a dominant visual sensory preference.

Furthermore, the results of this in-depth interview revealed that digital media acts as a bridge, transforming abstract and intangible mathematical concepts into concrete forms (concrete pictures). This phenomenon is clear in understanding the concept of limits, where informant INF-01 was only able to construct a complete mathematical understanding when viewing a dynamically moving graph approaching a certain line on a computer screen. This dynamic visualization provides an intuitive learning experience, helping students grasp the essence of changing variable values and function behavior in real time, which is difficult to achieve if relying solely on mental imagery or static scribbles on paper.

In addition to the graphical movement aspect, aesthetic and structural elements such as color coding in digital media play a crucial role in simplifying the complexity of mathematical variables. Informant INF-01 emphasized that different color representations for each variable are very helpful in distinguishing between components that experience change (dynamic variables) and components that remain constant (constants). This color-based visual conditioning functions as an attention-guiding tool that minimizes spatial disorientation when the visual display on the screen shifts, so that students can maintain their logical focus in analyzing complex formula structures.

Session 2: Auditory Student Perspective

Interviewer	:	*In today's digital age, online learning platforms and resources are abundant. How do you view this, and what are your biggest challenges?*
INF-02	:	*My biggest challenge in this digital age is that too much material is presented solely in text form, such as e-books or thick PDF modules. For me, reading such long texts is tiring and difficult to digest.*
Interviewer	:	*So, what methods or media are most effective in helping you accelerate your understanding of math material?*
INF-02	:	*I find it much quicker to understand when I have a group discussion session on WhatsApp using the voice note feature, or when I listen to a lecturer's direct explanation.*
Interviewer	:	*What makes a lecturer's voice or verbal explanation different from reading a textbook independently?*
INF-02	:	*For me, the lecturer's voice emphasizes the most important logic in a theorem proof. Through the lecturer's intonation and pauses, I understand the key points of the formula, something I can't get from just reading a textbook.*

The abundance of digital learning resources in this modern era poses unique cognitive challenges for students with auditory learning styles. Informant INF-02 explicitly identified the dominance of static text-based materials, such as e-books and thick PDF modules, as a major obstacle to their learning process. For auditory learners, reading lengthy texts is tiring and difficult to digest independently. This suggests that the abundance of digital literature does not necessarily guarantee effective learning if its presentation ignores the varying sensory preferences of students, particularly those who rely on the auditory modality.

To overcome these text barriers, auditory learners rely on verbal interaction and interactive voice-based communication features to accelerate their understanding of mathematics material. Informant INF-02 emphasized that group discussion sessions via instant messaging platforms like WhatsApp, utilizing the voice note feature, and listening to lecturers' live explanations, proved far more effective in accelerating their understanding. These findings indicate the importance of the flexibility of digital media, which functions not only as a repository of text documents but also as a space for verbal interaction that allows for acoustic dialogue and the auditory exchange of ideas.

Furthermore, the results of this in-depth interview revealed that paralinguistic elements in the lecturer's voice have a crucial function as logical scaffolding that cannot be replaced by conventional textbooks. Informant INF-02 explained that the lecturer's verbal voice can emphasize the most essential logical parts in a theorem proof. Through the play of intonation, rhythm, and pauses when the lecturer speaks, auditory students can identify key points and the mathematical structure of a formula more easily. Thus, aspects of verbality and oral articulation function as cognitive focus guides that help students systematically map out complex mathematical thought processes.

Synthesis of Findings: Adapting in the Digital Era

A synthesis of the three data sources shows that technology integration in the digital era significantly strengthens and emphasizes the unique characteristics of each student's learning style. Digital technology acts as a cognitive accelerator for visual learners through the presentation of dynamic data visualizations and interactive graphic manipulation. Conversely, the same digital platforms also create inclusive spaces for auditory learners to repeatedly retain material using audio-visual recordings, voice messaging features, and verbal interactions. This digital transformation does not change students' basic preferences but rather provides an ecosystem that enriches learning tools tailored to their sensory needs.

These findings empirically confirm that the success of mathematics learning at Muhammadiyah University of Makassar is highly dependent on the availability and development of adaptive learning media. To optimize clinical learning outcomes for abstract material, instructional designs designed by lecturers must be able to simultaneously converge strong visual elements with articulate auditory explanations. This recommendation calls for a shift from the one-way and monotonous use of technology to a multimodal platform that not only facilitates student learning independence but also bridges diverse sensory modalities to achieve comprehensive mathematical understanding.

Discussion

Convergence of Learning Styles and Multimedia Cognitive Theory

The findings of this study indicate that the dominance of visual learning styles, which reached 55% among Mathematics Education students at the University of Muhammadiyah Makassar, strongly aligns with the cognitive theory of multimedia learning developed by Richard Mayer. According to this theory, humans process information through two separate channels: the auditory and the visual channels (Bechtold, 2023; Mayer, 2024). In today's digital era, students' visual channels are intensively stimulated using mathematical software such as GeoGebra and various other interactive media. These results also reinforce a previous study, which confirmed that the integration of digital visualizations significantly improves students' cognitive retention in complex courses such as mathematics (Cirneanu & Moldoveanu, 2024; Fokuo et al., 2023).

However, the most interesting phenomenon of this finding lies in the cognitive adaptation mechanisms demonstrated by auditory students (35%) in exploring digital media. Although mathematics is inherently a visual-spatial discipline, auditory students at the University of Muhammadiyah Makassar indicated that verbal explanations—such as those obtained through voice notes or educational podcasts—serve as "logical anchors." This sound-based instrument significantly assisted them in organizing and systematically arranging the steps of mathematical proofs. This adaptive characteristic demonstrates that visual limitations are not an absolute barrier if the digital ecosystem provides an accommodating space for the auditory modality.

Theoretically, the cognitive interaction between these two groups of students provides strong empirical support for Allan Paivio's Dual Coding Theory. This theory states that the integration of simultaneously presented verbal and visual representations can create much stronger memory traces in the brain than the use of either modality in isolation (Burns et al., 2020; Paivio, 2014). In the context of mathematics learning in the digital age, the convergence of dynamic visual stimulation and articulate auditory explanations not only facilitates a variety of heterogeneous learning styles but also optimizes students' working memory capacity in constructing an understanding of abstract mathematical concepts (Weigand et al., 2024).

Transformation of Learning Styles in the Digital Age: Shifting from Static to Dynamic

There has been a fundamental shift in student learning behavior because of the massive penetration of digital technology. While classic research such as that conducted by Hattie and O'Leary (2025) positioned learning styles as fixed sensory tendencies, the results of this study demonstrate the existence of dynamic multimodal adaptability in students. Visual learners in the digital age no longer simply stare at static images or inanimate diagrams in conventional textbooks but rather actively interact with dynamic visualizations. This transformation indicates that rigid boundaries between learning modalities are now beginning to dissolve and integrate, forming a new cognitive flexibility in the digital ecosystem.

While a previous study by Lowrie and Diezmann (2007) emphasized the importance of graphical skills in mathematics, this study's findings go further by revealing students' internal mechanisms. In the digital age, visual learners demonstrate a strong tendency to exploit the manipulative features of mathematical applications to independently construct their own conceptual understanding. This phenomenon confirms that the presence of digital technology has successfully shifted the orientation of visual learning styles, from passive-receptive information absorption to active-constructive (Thianthai & Tamdee, 2022). This paradigm shift has important implications: digital interactivity can transform the way students manipulate abstract objects into concrete representations that are meaningful to their cognitive processes.

The Challenges of Cognitive Load and Differentiated Learning

Observations show that students experience a "cognitive deadlock" when faced with dense digital text empirically confirm the cognitive load theory developed by John Sweller (Sweller, 2023; Szulewski et al., 2022). In the context of students at Muhammadiyah University of Makassar, this excessive cognitive load arises when the characteristics of digital media are not aligned with their learning style modalities. For example, when auditory learners are forced to analyze complex mathematical material solely through static PDF documents without verbal explanations, they experience a surge in extraneous cognitive load. This cognitive load, irrelevant to the substance of the material, ultimately depletes students' working memory capacity, thus hindering the retention and understanding of the concepts being studied.

This research finding aligns with a previous study by Puspitarini and Hanif (2019), which stated that the effectiveness of learning media in higher education is highly dependent on its suitability to students' learning styles. Nevertheless, this research provides additional theoretical contributions by emphasizing that in the digital era, lecturers do not need to produce fragmented or distinct learning media exclusively for each individual student. Instead, lecturers are advised to adopt the Universal Design for Learning (UDL) approach when designing learning media. Developing multimodal media that simultaneously integrates text, dynamic graphics, and audio explanations has been proven to accommodate the needs of both visual and auditory learners without marginalizing either group, thus creating a more inclusive and efficient mathematics learning ecosystem.

Implications for Prospective Mathematics Educators

As students in the Mathematics Education study program, the subjects of this study are prospective teachers. Their awareness of their personal learning styles in the digital age has long-term pedagogical implications. If students (as prospective teachers) understand how technology can facilitate visual and auditory learning styles, they are more likely to implement similar differentiated learning strategies when they teach in schools.

This connects the findings of this study to the concept of TPACK (Technological Pedagogical Content Knowledge). Mastery of TPACK is not only about the ability to use digital tools, but also about the wisdom of selecting tools that suit the cognitive characteristics of students. Therefore, the results of this research at Muhammadiyah University of Makassar confirm that digital literacy for mathematics students must be accompanied by an understanding of learning psychology to create an inclusive educational ecosystem in the future.

4. CONCLUSION

The results of this study indicate that the learning styles of mathematics education students at Muhammadiyah University of Makassar in the digital era are dominated by visual (55%) and auditory (35%) tendencies, with visual learners excelling in interactions with dynamic visualizations, while auditory learners rely on interactive discussions to construct procedural logic. This finding confirms that although the digital era has not changed the basic types of learning styles, there has been a significant shift toward multimodal adaptability through the independent use of technological features to overcome the limitations of unipolar material. Practically, this study recommends the implementation of Differentiated Learning strategies and a Universal Design for Learning (UDL)-based curriculum that integrates interactive visual elements and clear auditory narratives to minimize barriers to understanding abstract concepts and optimize students' mathematical literacy.

As suggestion, it is recommended that mathematics education study program managers and lecturers at Muhammadiyah University of Makassar begin integrating instructional design based on the Universal Design for Learning (UDL) approach by providing digital teaching materials that simultaneously synergize dynamic visualizations and explicit auditory explanations. In addition, institutions need to provide cognitive literacy training for students so that they are able to identify and optimize their personal learning styles in utilizing artificial intelligence technology and mathematical software, so that digital transformation in the higher education environment does not only stop at the availability of infrastructure but is also able to touch the essence of increasing the understanding of mathematical concepts in depth and inclusive.

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