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The 4 Mode Application Techniques Learning Model in Science Education: Analysis of Global Trends, Impacts, and Opportunities in Indonesia

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Abstract

Background and Aim: The limited research and literature on implementing the 4 Mode Application Techniques (4MAT) instructional model in Indonesia makes it challenging for educators to obtain sufficient information on how to adapt this model within the local context. This study analyzes global trends, challenges, and opportunities of the 4MAT instructional model in science education within the Merdeka Curriculum framework.

Materials and Methods: The research employs a mixed-method approach, incorporating quantitative bibliometric analysis and qualitative systematic literature review using the PICOA framework. Data were collected from the Scopus, Web of Science, Dimensions, Lens, and Google Scholar databases from 2014 to 2024.

Results: The findings indicate that the 4MAT instructional model encompasses five key concepts: instructional method implementation, learning models, learning styles, conceptual understanding, and teaching strategies. The 4MAT instructional model impacts mathematics and science education, which the Merdeka Curriculum can support through various aspects, including diverse learning styles and cognitive skills, cognitive approaches and memory reinforcement, student motivation and engagement, enhancement of critical thinking and creativity, collaboration and social skills, real-world relevance and sustainability, and a well-structured learning framework. Challenges in implementing the 4MAT instructional model include intensive teacher training, limited resources and infrastructure, time constraints and implementation complexity, student readiness and learning style diversity, complex assessment and evaluation processes, curriculum alignment, and topic limitations. However, the Merdeka Curriculum presents opportunities through continuous professional development, utilizing creative resources, flexibility in instructional planning, and adapting more inclusive and differentiated teaching strategies.

Conclusion: In conclusion, the 4MAT instructional model offers a thorough approach to improving math and science instruction that supports the Merdeka Curriculum. Despite implementation issues, its integration can support inclusive, engaging, and fruitful learning experiences when combined with professional development and adaptable strategies.

Keywords: 4MAT; Learning Model; Merdeka Curriculum; Science Education

Introduction

The Indonesian education system faces various structural and policy-related challenges that impact the quality of science learning. Education in Indonesia remains entrenched in traditional routines that prioritize high exam scores (Muttaqin, 2018). Although the national curriculum has undergone multiple revisions to emphasize the development of 21st-century competencies (Herlinawati et al.,

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2024), its implementation in the field continues to be hindered by several factors, including a shortage of well-trained human resources (Pratikno et al., 2022), limited infrastructure (Haq, 2024), and disparities in educational access across regions (Mariyono, 2024). These constraints have resulted in a lack of space to adopt innovative instructional models.

The rigidity of educational standards in Indonesia often emphasizes rote learning over deep conceptual understanding. Science education in Indonesia remains predominantly theoretical, providing minimal opportunities for exploration and real-world application (Nugroho et al., 2021; Syarif et al., 2023). The prevailing instructional approach prioritizes memorizing scientific concepts (Nugraha, 2023) rather than fostering students' ability to comprehend and apply scientific principles in everyday life (Karno et al., 2024; Firdaus, 2025). Consequently, science education in Indonesia requires an innovative instructional model capable of addressing national and global challenges.

Global trends in science education reflect a paradigm shift toward more innovative and interdisciplinary instructional methodologies (Xi et al., 2024; Johnson & Czerniak, 2023; Zhan et al., 2022). One of the pedagogical models that has gained considerable attention in science education is the Four Mode Application Techniques (4MAT). The 4MAT instructional model offers a comprehensive and transformative approach. The 4MAT model reconfigures learning styles into strategic instructional frameworks, making it a highly applicable model for classroom implementation (ÖVEZ, 2012). This model emerged from recognizing that learners exhibit diverse and unique learning styles, necessitating instructional designs that accommodate the needs and interests of all students (McCarthy, 1997).

Challenges in Indonesian Education

The implementation of the 4MAT model in science education in Indonesia holds significant potential, particularly in alignment with the Ministry of Primary and Secondary Education's vision to enhance educational quality (Mendikdasmen, 2024) and the Ministry of Higher Education's goal of positioning Indonesia as a competitive global player (Wamendiktisaintek, 2025). The 4MAT instructional model can contribute to the development of a more adaptive curriculum that caters to students with diverse learning styles (Hibi, 2024; Panezai, 2022) while also promoting a more holistic approach to science education (Martínez et al., 2018). The 4MAT learning cycle fosters a personalized and continuously evolving learning environment, encouraging student engagement, curiosity-driven exploration, the development of experimental mindsets, and the practical application of knowledge (Sangchan et al., 2022).

The 4MAT instructional model has significant potential to enhance the quality of education, as it effectively accommodates diverse student learning styles and fosters meaningful learning experiences (Yanti et al., 2021; Thadee et al., 2024). While the 4MAT model has been proven effective in science education across several countries, including Turkey (Ilkorucu et al., 2022; Alanazi, 2020), Thailand (Thadee et al., 2024), and Egypt (Sabry et al., 2021), and been employed to develop various student competencies in Europe (Fickl et al., 2020; Nicoll-Senft & Sider, 2009), its implementation in Indonesia remains limited and suboptimal. A deeper analysis of the factors contributing to its low adoption is necessary to gain a more comprehensive understanding of the existing barriers and identify opportunities to facilitate its integration into the educational system.

Several key factors contribute to the low adoption of the 4MAT model, including time constraints (Aktas et al., 2015; Chittiwattanakorn & Sookkheo, 2017), implementation complexity (Martínez et al., 2018), teacher preparedness (Eze et al., 2024; Somsak et al., 2023), and student readiness (Martinez et al., 2017). Although the 4MAT model offers a holistic approach that supports the development of multiple intelligences, many educators in Indonesia remain unfamiliar with its concepts. Consequently, numerous schools and educational institutions rely on conventional teaching methods, such as lecture-based instruction and textbook-driven learning, which often overlook the diversity of students' learning styles (Yuwanita et al., 2020; El-Sabagh, 2021).

The scarcity of research and literature on implementing the 4MAT instructional model in Indonesia hinders educators from accessing adequate information on adapting this model within the local educational context. Despite international studies demonstrating positive outcomes (Ilkorucu et al., 2022; Alanazi, 2020; Thadee et al., 2024; Sabry et al., 2021; Fickl et al., 2020; Nicoll-Senft & Sider, 2009), the lack of research focused on contextualizing the 4MAT model within Indonesia's education system has led to reluctance among teachers and policymakers to explore its potential. This problem

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creates a cycle of limitations, as the absence of comprehensive studies on its adaptation within the local context continues to impede its adoption.

The limited adoption of the 4MAT instructional model in Indonesian science education is critical, as it directly affects the overall quality of education. Science education prepares Indonesia's younger generation to navigate increasingly complex global challenges (Syahriani & Yufriadi, 2023). The 4MAT model holds substantial potential to drive transformative change in science instruction by fostering a more holistic and interactive learning experience (Martínez et al., 2018), aligning with the demands of the modern era. Science education in several developed countries is not solely focused on theoretical mastery but also emphasizes developing practical skills and interdisciplinary thinking abilities (AlAli, 2024; Johnson & Czerniak, 2023).

Potential of 4MAT

The 4MAT instructional model can create learning experiences that integrate cognitive and affective aspects, making it particularly relevant in this context. Based on principles of human psychology, learning theories, and neuroscience, 4MAT combines these elements into a structured learning cycle, providing a holistic perspective on fundamental differences in how individuals perceive, process, understand, and communicate information (McCarthy et al., 1990; 2002). Consequently, 4MAT not only enables students to grasp scientific concepts but also allows them to experience, apply, and develop essential skills for solving problems creatively.

The 4MAT instructional model has been proven effective in enhancing students' critical thinking and creativity. Research by Zhang and Wang (2024) indicates that implementing the 4MAT model in classroom interactions not only improves critical thinking skills but also strengthens the "4Cs" creativity, communication, and collaboration, which are essential for students to navigate modern global challenges. Ilkorucu et al. (2022) and Aktas & Bılgın (2015) found that this model positively influences students' learning motivation, particularly in science education. While these studies highlight the significant potential of the 4MAT model in enhancing motivation and critical thinking abilities, further research is needed to evaluate its implementation and effectiveness within the Indonesian educational context.

This study holds significant potential to contribute to science education in Indonesia while striving to create more relevant and compelling learning experiences globally. One of its key contributions is providing a deeper understanding of the local challenges faced by Indonesia's education system in adopting innovative instructional models like 4MAT. By aligning the findings of this research with the implementation of the Merdeka Curriculum, which is currently being adopted in Indonesia, this study aims to offer more precise insights into how a more flexible and student-centered learning approach can be effectively implemented. Merdeka Curriculum emphasizes the importance of granting schools and teachers greater autonomy in developing instructional methods suited to local contexts and students' needs (Jasiah et al., 2024; Hunaepi & Suharta, 2024); however, ensuring consistent and effective implementation remains a challenge.

Objectives

This research will map global trends relevant to applying the 4MAT instructional model in science education, identifying key factors influencing its success. Beyond providing an overview of global trends, this study will formulate strategies for its implementation within Indonesia's educational landscape. Therefore, this research will identify the strengths, challenges, and opportunities of adopting the 4MAT model. The analysis will also introduce new perspectives on how Indonesia's education system can evolve toward a more experiential and application-based approach, aligning with global demands that increasingly emphasize 21st-century skills.

Literature Review

4MAT Learning Model

The 4MAT Learning Model, developed by Bernice McCarthy, is an instructional framework that integrates various learning styles and brain-based research to improve teaching and learning effectiveness (McCarthy, 2000). It consists of four distinct learning modes—experiencing, conceptualizing, applying, and refining—which are mapped to Kolb's experiential learning cycle and

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hemispheric brain processing. The model emphasizes a cyclical structure of learning, allowing students to engage with content in ways that match their preferred cognitive processes while also strengthening less dominant styles (Kolb, 1984). This approach is particularly effective in creating balanced instruction that reaches a wide range of learners.

Structure of the 4MAT Model

The 4MAT model organizes learning into four quadrants based on a combination of "perception" (feeling vs. thinking) and "processing" (reflecting vs. doing) dimensions. Mode 1 learners prefer reflective observation and concrete experiences, thriving on personal meaning and human connection. Mode 2 learners are abstract thinkers who favor conceptual understanding and analytical thinking. Mode 3 learners prefer practical application and active experimentation, seeking usefulness and relevance. Mode 4 learners are dynamic and innovative, enjoying self-discovery, experimentation, and integrating learning into their own frameworks (McCarthy & McCarthy, 2006). Each mode leads into the next, creating a comprehensive learning cycle that supports diverse cognitive needs.

Application Techniques in Each Mode

Each mode of the 4MAT model suggests specific instructional strategies. For Mode 1 (Why?), teachers might use storytelling, personal reflection, or discussions that build emotional connection to the topic. For Mode 2 (What?), direct instruction, lectures, readings, and structured analysis help learners acquire theoretical knowledge. In Mode 3 (How?), hands-on activities, problem-solving exercises, and skill practice facilitate application of concepts. Finally, Mode 4 (What if?) encourages creativity and self-directed learning through projects, role-playing, simulations, or open-ended investigations (McCarthy, 2000). These techniques ensure that students engage in a complete cycle of learning, deepening their understanding through varied experiences.

Benefits of the 4MAT Model

The 4MAT model has been found to improve student engagement, retention, and critical thinking by aligning instruction with different learning preferences (Dunn & Griggs, 2003). Its application fosters student autonomy, creativity, and collaborative learning by encouraging learners to move through the full cycle rather than remain confined to a single preferred mode. Particularly in STEM fields, such as mathematics and science, this model promotes both conceptual understanding and practical application, which are essential for meaningful learning (Caine & Caine, 1991). Moreover, the model supports differentiated instruction, making it an effective strategy in diverse and inclusive classrooms.

Challenges and Considerations

Despite its benefits, implementing the 4MAT model poses challenges. It requires thorough planning, an understanding of learning theory, and often a shift in traditional teaching practices. Teachers must be trained to design lessons that flow through all four modes, which can be time-consuming and complex. Additionally, assessments must be aligned with multiple instructional techniques, demanding flexible and authentic evaluation tools (McCarthy & McCarthy, 2006). Schools may also face limitations in resources, time, and curriculum alignment, which can hinder effective adoption.

In conclusion, the 4MAT Learning Model represents a powerful instructional approach that integrates theory and practice to accommodate diverse learning styles. Its application techniques offer structured yet flexible strategies that promote deep and sustained learning. When effectively implemented, the 4MAT model not only enhances academic achievement but also nurtures students' cognitive, emotional, and creative capacities. As education systems like Indonesia's Merdeka Curriculum emphasize differentiated and student-centered learning, models like 4MAT are increasingly relevant in fostering well-rounded, future-ready learners.

Methodology

This study employs a mixed-methods research approach, integrating quantitative and qualitative analyses to examine research trends, the impact, and the opportunities associated with the 4MAT instructional model in science education in Indonesia. The study utilizes scholarly articles from Scopus, Web of Science, Dimensions, Lens, and Google Scholar, covering the period from 2014 to 2024. The sample selection process was conducted using article titles, abstracts, and keywords,

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employing the search terms "4MAT learning model" OR "4MAT" OR "4MAT SYSTEM" OR "4 MODE APPLICATION TECHNIQUES."

Two analytical approaches addressed the research questions: bibliometric analysis and systematic literature review (SLR). Both analyses used the same dataset, each with distinct input, process, and output indicators designed to answer the research questions effectively. The research framework is illustrated in Figure 1.

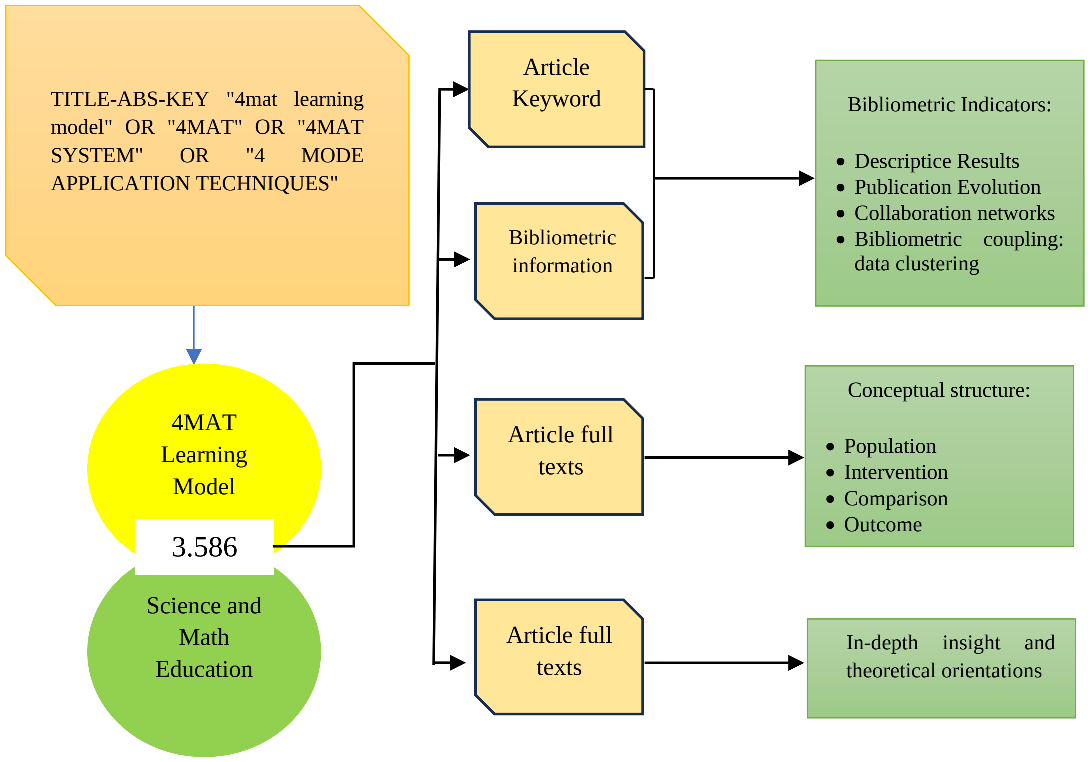

Figure 1. Research Framework Design

Bibliometric Analysis

Bibliometric analysis is a statistical approach that facilitates exploring and examining extensive scientific data to uncover patterns and highlight developments within a specific field (Donthu et al., 2021). The purpose of employing bibliometric analysis in this study is to identify research trends and collaboration networks (Firdaus et al., 2025) related to the 4MAT instructional model through bibliometric statistical tools.

This analysis incorporates several quantitative publication metrics, including the number of articles published, citation frequency, keyword frequency, subject categories, and country contributions. The study focuses on the number of publications, co-authorship networks, and trending topics over the past decade. The number of publications provides insights into shifts in scholarly interest in 4MAT research, while subject categories illustrate the model's application across various disciplines. Additionally, the distribution of reference sources highlights how research related to the 4MAT model has been disseminated across academic journals (He et al., 2020).

This study employs VosViewer (Visualization of Similarities) for bibliometric analysis. VosViewer is a Java-based software designed to visualize and explore bibliometric knowledge networks (Leydesdorff & Rafols, 2012). This tool offers a clustered mapping approach to establish connections across various bibliometric needs, providing interactive and accessible visualizations of bibliometric networks, making it superior to alternative software (van Eck & Waltman, 2010). The clustering algorithm operates with adjustable Y-parameters, and both cluster density and color can be modified within VosViewer for enhanced data visualization (Leydesdorff & Rafols, 2012).

Systematic Literature Review

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A Systematic Literature Review (SLR) involves a rigorous and structured evaluation of scholarly articles to identify key themes, methodologies, and contributions within the literature (Pinna, 2020). This study employs SLR to gain deeper insights into the impact and opportunities of implementing the 4MAT instructional model in science education.

The SLR method minimizes bias by systematically synthesizing scientific evidence, ensuring a comprehensive and objective evaluation of relevant research. This method follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which provide an evidence-based reporting framework for systematic reviews (Page et al., 2021). The PRISMA procedure includes identification, screening, eligibility assessment, and inclusion criteria (Şalvarlı & Griffiths, 2021).

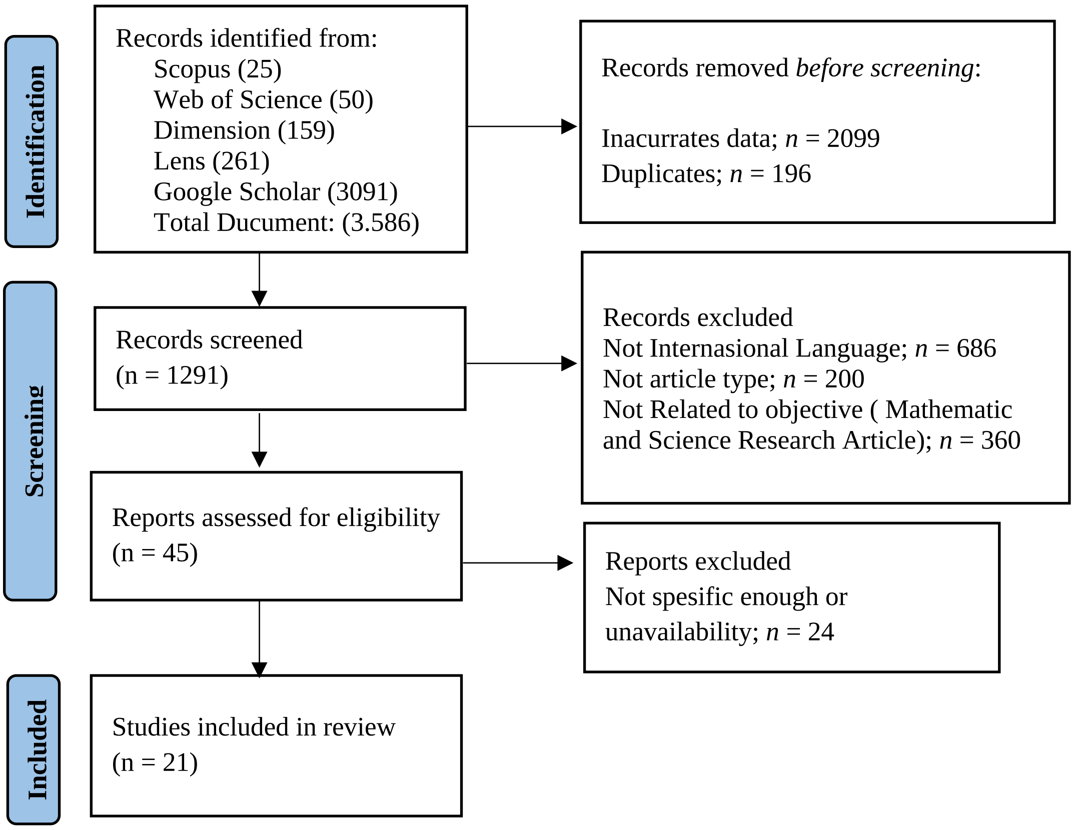

Figure 2. PRISMA Systematic Literature Review to show the study-selection process

PICOA

The impact and opportunities for implementing the 4MAT learning model in science education in Indonesia were analyzed in this study using the PICOA (Population, Intervention, Comparison, Outcome, and Adaptation) conceptual framework. As outlined in Table 1, the PICOA framework facilitates an in-depth analysis of various factors influencing the application of the 4MAT learning model within the Indonesian education system, including students, teachers, science learning materials, challenges, and the model's alignment with the national curriculum.

Table 1. PICOA Framework

Population/problem	**Students, teachers, and science learning materials**
Intervention	Research Methods Used
Comparison	Comparison of learning models
Outcome	Student learning outcome variables
Adaptation	Advantages, challenges, conformity with the national curriculum

The population of the core issue under investigation focuses on the primary research subjects. The intervention refers to the research methodology employed in this study. The comparison aspect is

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analyzed using different instructional methods in experimental and control classes, providing measurable research findings. Meanwhile, adaptation considers the local context by examining the model's strengths, challenges, and compatibility with the national curriculum. The PICOA framework is a guiding tool to explore the impact and feasibility of the 4MAT learning model in science education and the challenges encountered during its implementation in Indonesia.

Results

Publication Evolution

The evolution of research publications on the 4MAT instructional model in education, as derived from five databases (Scopus, Web of Science, Dimensions, Lens, and Google Scholar), as illustrated in Figure 3, reveals an intriguing development pattern and highlights shifts in academic interest in this topic over the past decade.

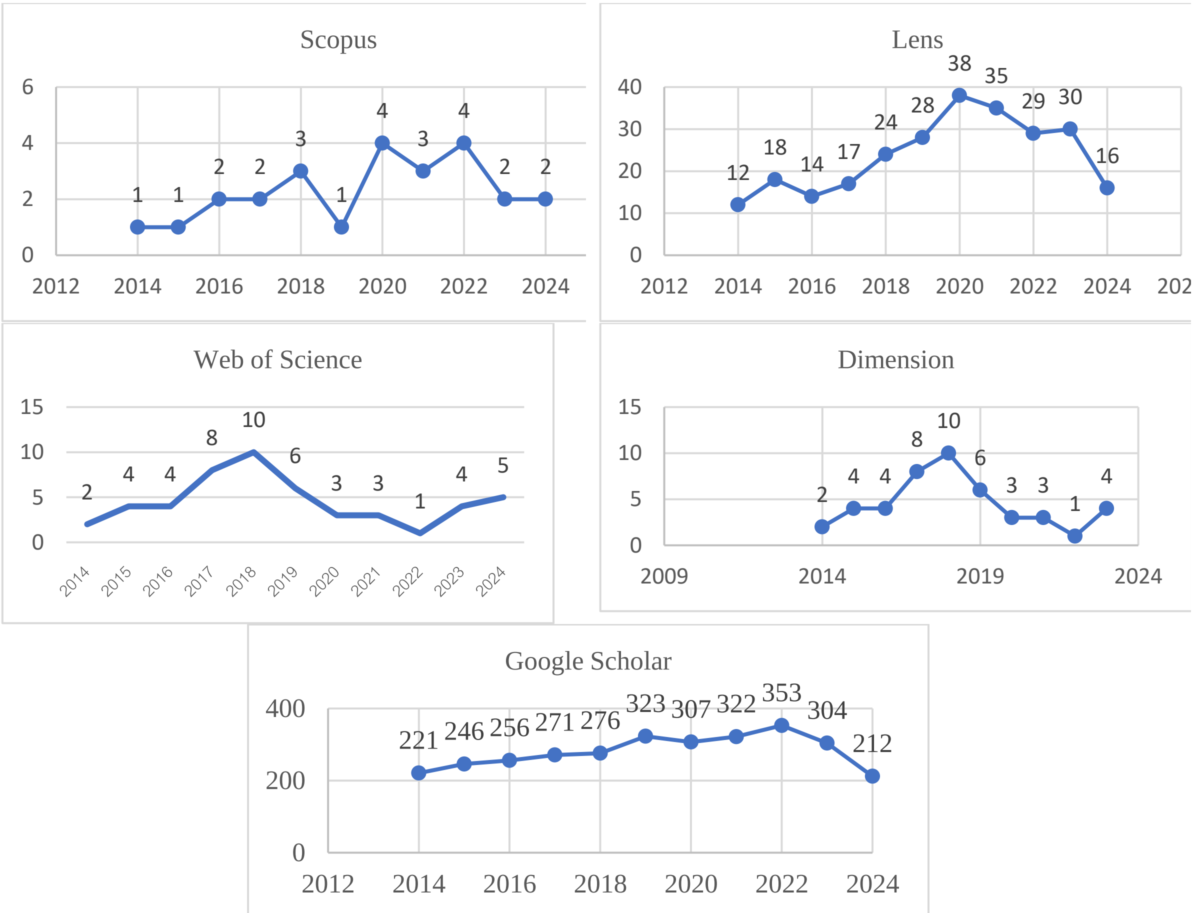

Figure 3. Publication Evolution

The Scopus database exhibits a relatively stable trend with minimal fluctuations. While the number of publications did not experience a significant surge, a notable increase was observed in 2020 and 2022, with total publications reaching four in each of these years. This result indicates a heightened interest in the topic during those years, albeit with a relatively low publication count compared to other databases. Lens demonstrates a steeper surge, peaking in 2020 with 38 publications, marking the highest number recorded throughout the observation period. However, this trend was followed by a significant decline in 2022 and 2024, suggesting that although the 4MAT instructional model garnered substantial attention in 2020, interest in the topic gradually diminished. Despite this decline, Lens remains one of the databases with a consistently high publication count over multiple years. Web of Science displays more significant fluctuations in publication volume. In 2018, it recorded 10 publications, the highest within that period. However, this was followed by a sharp decline in 2020 and 2021. After this downturn, the number of publications in Web of Science gradually increased again in 2024. This trend

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may reflect shifts in research priorities or waning interest in the 4MAT instructional model during specific periods. Dimensions exhibit a trend like Lens, with increased publications in 2020 and 2022. In 2020, the number of publications reached 23, rising to 26 in 2022 before experiencing a decline in 2024. This result suggests that Dimensions and Lens recorded significant interest in this topic during periods, yet both databases also saw a subsequent drop in publication volume. In contrast, Google Scholar presents a distinct trend, characterized by steady growth from 2014 onwards, peaking in 2022 with 353 publications. This figure is significantly higher than those recorded in other databases, indicating that Google Scholar maintains a higher consistency in publication volume and has experienced a more rapid increase than other platforms. However, after reaching its peak in 2022, the number of publications in Google Scholar declined, though it remained higher than in previous years.

Collaboration Analysis

Collaboration among authors is closely linked to frequently discussed topics and emerging trends over the past decade. The co-authorship analysis identified 2,216 authors across 1,291 analyzed documents. To maintain analytical precision, a maximum limit of 25 authors per document was set, while the minimum threshold for an author's contribution was two publications, resulting in 292 identified collaboration thresholds. The findings of the author collaboration analysis are illustrated in Figure 4.

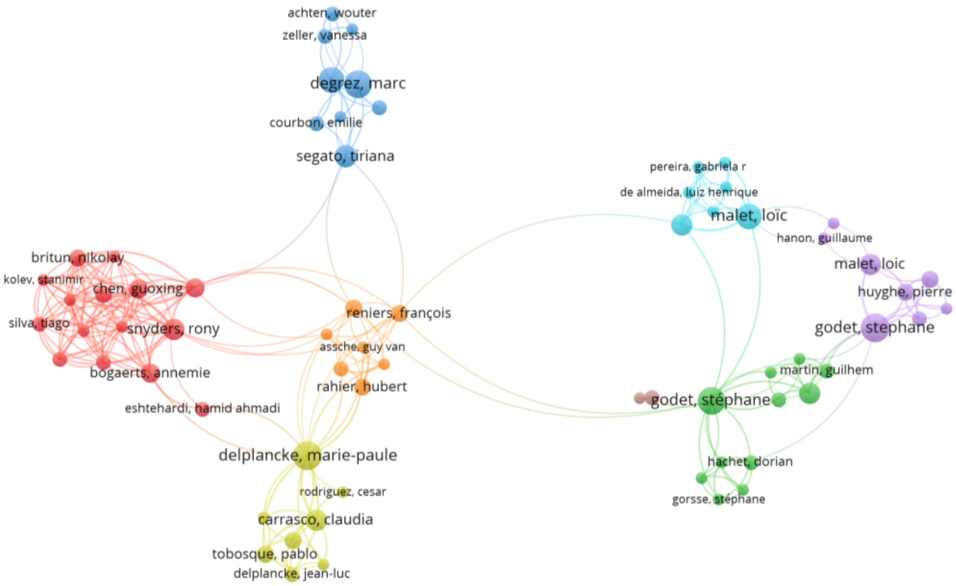

Figure 4. Authorship Collaboration

This study employs network visualization analysis based on research domains, focusing on titles and abstracts. The selected counting method is complete counting, yielding 5,041 terms. The analysis was conducted by setting a minimum occurrence threshold of 10, resulting in 105 terms meeting the threshold. However, further calculations were performed to refine the topics for relevance. Based on the relevance scores obtained, the most relevant terms were further filtered, with 60% of the most relevant terms selected by default, leading to a final selection of 63. Verification of term selection was still carried out to ensure the inclusion of appropriate terms. Terms such as 4MAT system and Bernice McCarthy were excluded from verification since they are primary keywords under discussion rather than indicators of a specific research domain. Similarly, generic terms such as system, unit, appendixes, paper, type, question, part, page, application, light, information, chapter, and article were omitted, as they do not precisely represent a research field.

Beyond authorship collaboration, which has been essential for identifying key experts in the 4MAT instructional model over the past decade, further attention is needed to examine the conceptual relationships within the context of 4MAT implementation in education. This result is crucial for understanding the integration of frequently discussed topics related to 4MAT. The conceptual relationship analysis identified five clusters with 298 links and a total link strength of 1,534, as illustrated in Figure 5.

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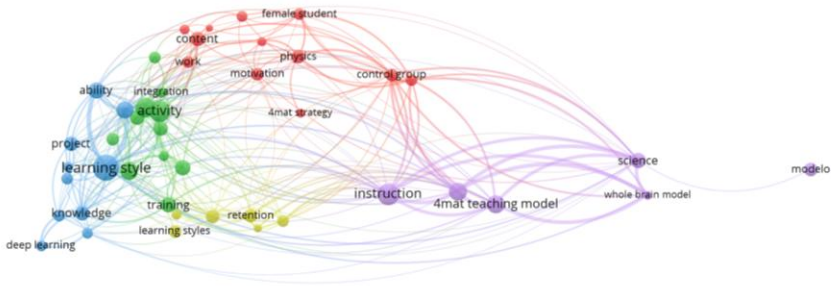

Figure 5. Concepts related to the 4MAT learning model

The first cluster, represented in red, emphasizes implementing the 4MAT instructional methods to accommodate diverse student learning styles and enhance motivation. Concepts such as "4MAT Instruction Method," "Strategy," and "Physics" indicate the model's broad applicability across subjects, including the specific considerations of gender factors. Appropriately structured instructional methods significantly improve students' comprehension and integration of scientific concepts (Ilkorucu et al., 2022; Ursin, 1995). The cluster reflects the 4MAT model's versatility and motivational impact on education.

The second cluster, represented in green, highlights the practical implementation and activities integral to the 4MAT learning model. Key concepts like "Activity," "Cycle," "Framework," and "Integration" emphasize structured, experiential learning phases designed to foster knowledge integration and active student engagement. Training and workshops further support skill development in effectively applying this model (Uyangör, 2012). Thus, this cluster illustrates the importance of systematic execution and experiential learning within the 4MAT framework.

The third cluster, represented in blue, centers on students' learning styles and personalized instructional strategies within the 4MAT model. Concepts including "Deep Learning," "Experiment," and "Project" highlight experiential and applied approaches tailored to individual student preferences and abilities. The cluster underscores adaptability and personalization as key strengths of the 4MAT model (Isreb & Nag, 2006). Consequently, aligning instructional strategies with learning styles enhances deep learning and comprehension.

The fourth cluster, represented in yellow, focuses on the practical application of the 4MAT method regarding learning styles. It highlights tailoring instructional techniques ("Mode Application Technique") to improve students' attitudes, motivation, and knowledge retention, reflecting the model’s effectiveness in personalized education. This cluster emphasizes the role of learning styles in facilitating lasting academic achievement and student engagement.

The fifth cluster, represented in purple, underscores the importance of structured instructional methods within the 4MAT teaching model, particularly emphasizing scientific disciplines. Concepts such as "Academic Achievement," "Modelo," and "Whole Brain Model" highlight the comprehensive cognitive approach of 4MAT, integrating neuroscience principles to enhance student performance. Overall, the cluster highlights the effectiveness of an integrated instructional approach in improving science education outcomes.

From a global perspective on 4MAT trends in science education, as illustrated in Figure 6, there are 20 links with a total link strength of 174 and an occurrence rate of 22.

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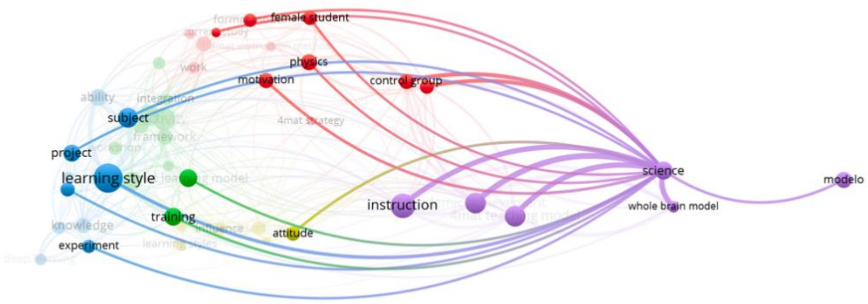

Figure 6. Conceptual relationships within science education

Figure 6 illustrates the strong interconnection between various concepts in science education by implementing the 4MAT learning model. This study highlights the significant correlation between different learning aspects in applying the 4MAT model within the scientific domain. Concepts such as "Motivation," "Learning Style," "Instruction," and "Science" are closely linked, underscoring the critical role of adapting students' learning styles, fostering motivation, and employing effective instructional methods to enhance the quality of science education. With its holistic approach, the 4MAT learning model facilitates more personalized instruction, accommodating diverse learning preferences and inspiring students to engage more actively in the learning process.

Conceptual Framework

The population, presented in Table 2, encompasses various groups, including middle school (SMP) and high school (SMA) students, elementary school (SD) teachers, and prospective educators. Most studies focus on middle and high school students, covering subjects such as Mathematics, Physics, Chemistry, and Biology. Research involving middle and high school students typically includes a more significant number of participants, such as the study conducted by Eze et al. on middle school Chemistry, which involved 295 participants. In contrast, studies with smaller sample sizes, such as the research by Erşen & Güven on elementary school teachers in Mathematics, included only three participants.

Table 2. Research Population

Code	Author	Population		
		Subject	Number	Content
R1	Hibi (2024)	SMP	64	Math
R2	Tumanguil (2021)	SMA	76	Physics
R3	Panezai & Mahmood (2022)	SMP	72	Biology
R4	Jack & ZUBAIRU (2022)	SMA	205	Chemistry
R5	Ibenegbu & Nzewi (2020)	SMA	139	Biology
R6	Chittiwattanakorn & Sookkheo (2017)	SMA	41	Chemical
R7	Erşen & Güven (2018)	Teacher	3	Math
R8	Alanazi (2020)	SMP	41	Physics
R9	Sani & Salisu (2023)	SMA	104	Chemistry
R10	Aktas & Bılgın (2015)	SMP	235	Chemistry
R11	Omoniyi (2021)	SMP	180	Chemistry
R12	Aliustaoğlu & Tuna (2022)	Pre-Teacher	16	Math
R13	Ilkorucu et al (2022)	SMP	60	Biology
R14	Eze et al (2024)	SMP	295	Chemistry
R15	Somsak et al (2023)	SD	40	Physics

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Code	Author	Population		
		Subject	Number	Content
R16	Ismael (2020)	SMP	27	Chemistry
R17	Sabry et al (2021)	SD	89	Science
R18	Ismael et al (2021)	SMP	27	Chemistry
R19	Demircioğlu & Sezgin Selçuk (2016)	SMA	60	Physic
R20	Tezcan & Güvenç (2017)	SD	68	Science
R21	Şeker & Övez (2018)	SD	65	Math & Social Studies

Note: SD (Elementary School), SMP (Junior High School), SMA (Senior High School)

Table 3 presents interventions, method comparisons, and outcomes from various studies related to the 4MAT instructional model. Most studies applied quasi-experimental methods and frequently compared the 4MAT model to traditional instructional methods. The common outcomes measured were academic achievement, motivation, and conceptual understanding.

Table 3. Research Intervention, Comparison, and Outcome

Research Intervention, Comparison, and Outcome	
Intervention	
Quasi-Experiment	R1, R4, R5, R8, R9, R10, R13, R14, R17, R19, R20, R21
True Experiment	R2, R3, R15
Experimental study	R7, R11, R16, R18
Mix-method	R12
CAR	R6
Method Comparison	
Traditional/Conventional/Regular Instructions/Lecture Method	R1, R2, R3, R5, R8, R9, R10, R11, R13, R14, R16, R17, R18, R19, R21
Demonstration	R4
Professional training	R7
Computer Simulation Instructional Package	R11
5E	R15
Whole Brain	R20
Inquiry	R20
Outcome	
Academic Achievement	R3, R4, R6, R10, R20, R21
Conceptions	R8, R11, R19
Attitude	R4, R16
Systemic Thinking	R1
Problem-Solving	R2
Multiple Intelligence	R5
Working Memory	R4
Connection Skills	R6
Teacher Perceptions	R7

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Research Intervention, Comparison, and Outcome	
Academic Performance	R9
Retention	R9
Motivation/Interest	R10, R14, R18
PCK	R12
Critical Thinking Disposition	R13
Creative	R15, R17
Awareness	R18

Most studies utilized a quasi-experimental approach, reflecting a practical research setting. Traditional instructional methods were the predominant comparison, indicating a preference for evaluating 4MAT against conventional practices. Furthermore, Academic achievement, conceptual understanding, and student motivation emerged as the most common outcomes, underscoring the effectiveness of the 4MAT model in improving essential educational metrics.

Challenges of Implementing the 4MAT Model:

1. Time constraints in curriculum execution.
2. Complexity of the 4MAT implementation process.
3. Limited teacher preparedness and training opportunities.
4. Resource limitations, particularly in rural or remote educational settings.

Benefits of Implementing the 4MAT Model:

1. Enhanced student motivation and engagement.
2. Improved academic achievement and retention of knowledge.
3. Accommodates diverse student learning styles, promoting inclusivity.
4. Strengthens critical thinking, creativity, and problem-solving skills.

The Impact of the 4MAT Learning Model on Mathematics and Science Subjects in the Merdeka Curriculum

Implementing the 4MAT learning model in mathematics and science education can support various aspects of the Merdeka Curriculum. The 4MAT model offers an adaptive and structured learning approach that aligns with diverse student learning styles while fostering critical and creative thinking skills and enhancing engagement in the learning process. The impact of the 4MAT learning model on mathematics and science subjects and its relevance to the Merdeka Curriculum is presented in Table 4.

Table 4. The 4MAT learning model Impact and relevance to the Merdeka Curriculum

Aspects	Code	Impact	Related
Diversity of Learning Styles and Thinking Skills	R1; R3; R5; R9; R21	The 4MAT learning model adapts to different learning styles of students so that each student can develop deep thinking and understanding skills (R1, R3, R5). This research supports the Merdeka Curriculum approach that focuses on student-centered learning and encourages the development of critical and creative thinking (R9, R21).	This aspect supports the intracurricular element by providing an in-depth contextual learning experience in line with the principles of critical and creative reasoning in the Pancasila Student Profile.
Cognitive Approach and Memory Reinforcement	R2; R6; R15;	The cognitive approach in 4MAT is practical in learning complex science materials, such as physics and chemistry, and can improve students' memory and comprehension (R2, R15). Structured activities help students internalize concepts better (R6).	Related to intracurricular that emphasizes deep and meaningful learning and developing critical reasoning skills.

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Aspects	Code	Impact	Related
Student Motivation and Engagement	R10; R14; R19;	The 4MAT learning model increases student motivation and makes students actively involved in the learning process (R10, R14). This involvement strengthens students' confidence and fosters a greater interest in science lessons (R19).	This approach is relevant to the cultural aspects of the school and intracurricular activities. It aims to create a learning climate that supports independent development and student motivation to learn actively.
Enrichment of Critical Thinking Disposition and Creativity	R13; R15; R17;	Enrichment of Critical Thinking Disposition and Creativity	This aspect supports the Pancasila Student Profile (P5) and intracurricular strengthening projects that target creative development and critical reasoning.
Collaboration and Social Skills	R5; R14; R17;	4MAT facilitates group activities and student collaboration, strengthening social skills and cooperation (R5, R14). Involvement in discussion and presentation activities helps students learn to respect the opinions of others and improve teamwork skills (R17).	This aligns with extracurricular aspects and school culture that foster the value of working together and strengthen the social skills needed in collaborative learning.
Relevance to Real Life and Sustainability	R13; R16; R18;	The 4MAT learning model enables students to understand the relevance of science materials to real-life issues, such as sustainability and environmental impact (R13, R16). Students who engage in these activities demonstrate a higher awareness of global issues (R18).	Supporting the Pancasila Student Profile (P5) is a strengthening project that facilitates contextual learning, encourages students to be globally diverse, and contributes to solving real problems.
Structured Learning	R21	The eight-phase structure in the 4MAT learning model provides a clear framework for teachers and students, making the learning process more structured and organized (R21).	Supporting intracurricular learning by providing guidance helps teachers design systematic learning which aligns with student needs and independent principles.

Based on the alignment analysis between the 4MAT learning model and key educational aspects, Table 4 summarizes how this model effectively caters to diverse learning styles and fosters essential educational outcomes aligned with the Merdeka Curriculum and Profil Pelajar Pancasila (P5) principles. The model is designed to adapt to various individual learning preferences through differentiated instructional methods, addressing the educational needs of a diverse student population. Furthermore, the 4MAT approach comprehensively addresses core educational objectives essential in contemporary curriculum design by focusing on developing cognitive, motivational, and social skills.

Regarding cognitive approach and memory enhancement, studies R2, R6, and R15 show that the cognitive framework embedded in the 4MAT learning model enhances students' retention and comprehension of complex scientific concepts, such as those in physics and chemistry. Its structured activities facilitate deeper internalization and conceptual mastery, allowing students to make meaningful connections between new knowledge and prior understanding. This aligns closely with the Merdeka Curriculum’s emphasis on meaningful learning, critical reasoning, and sustained intellectual development. Thus, the model actively supports students' cognitive growth by promoting deeper engagement with scientific materials.

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Regarding student motivation and engagement, studies R10, R14, and R19 highlight the effectiveness of the 4MAT model in significantly enhancing student motivation and active participation. This increased engagement and self-confidence foster a dynamic, student-centered learning environment consistent with Merdeka Curriculum principles, emphasizing intrinsic motivation and active involvement. By implementing varied interactive activities, the model successfully stimulates student interest and enthusiasm, creating an optimal environment for student-centered learning. Consequently, it reinforces students' motivation to learn, thus positively impacting academic achievement and classroom participation.

Concerning critical thinking and creativity, evidence from studies R13, R15, and R17 illustrates that the 4MAT learning model enhances students' disposition toward critical analysis and problem-solving abilities. The approach encourages students to explore problems from multiple perspectives, prompting innovative solutions and fostering flexible thinking. By aligning effectively with the Profil Pelajar Pancasila (P5) projects, the model supports creativity and critical reasoning within the classroom and helps students apply these skills to broader real-world contexts. This holistic development ensures that students are better equipped to navigate complex, real-life challenges.

The aspect of collaboration and social skills is demonstrated by studies R5, R14, and R17, revealing that the 4MAT model fosters essential social competencies through structured group activities and peer collaboration. Collaborative activities within the model encourage students to appreciate differing perspectives, promoting empathy and mutual respect. Additionally, through team-based assignments and discussions, students improve their communication and interpersonal skills, which are essential for cooperative learning environments. This aligns with the cultural values of gotong royong, significantly reinforcing students' abilities to engage effectively in teamwork and collaborative problem-solving.

Regarding real-world relevance and sustainability, studies R13, R16, and R18 indicate that the 4MAT learning model significantly increases students' awareness of critical global issues, including sustainability and environmental impacts. By contextualizing scientific concepts within real-world scenarios, the model makes learning more relevant and engaging, encouraging students to consider their roles as responsible global citizens. It supports the objectives of the Profil Pelajar Pancasila (P5) projects, emphasizing the practical application of learned knowledge to address and solve real-world problems. Therefore, students develop a robust understanding of sustainability issues and gain the capability to participate actively in environmental problem-solving.

The aspect of structured and organized learning, study R21 emphasizes that the systematic framework provided by the eight phases of the 4MAT learning model contributes to clear, structured instructional delivery, benefiting both educators and learners. This structured approach provides educators with explicit guidance for lesson planning, ensuring that instructional goals and student learning objectives are consistently met. Moreover, it promotes student independence by clearly delineating learning phases encouraging students to take ownership of their educational processes. This aspect is closely aligned with the Merdeka Curriculum’s focus on student-centered instruction and essential independent learning skills for navigating the demands of 21st-century education.

Opportunities for Implementing the 4MAT Learning Model in Indonesia’s Education Curriculum

The challenges and opportunities associated with implementing the 4MAT learning model within Indonesia’s education curriculum, particularly in the context of the Merdeka Curriculum, are outlined in Table 5.

Table 5. The challenges and opportunities with implementing the 4MAT learning model

Aspects	Code	Challenge	Opportunities
The Need for Intensive Teacher Training	R1, R14, R15, R21	Implementing the 4MAT learning model requires special and intensive training for teachers so that students can implement this method effectively. This requires	The Merdeka Curriculum makes teacher adjustments and training sustainably through teacher-driving programs and initiatives to improve teacher competence. This can be an opportunity to introduce 4MAT

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Aspects	Code	Challenge	Opportunities
		support through workshops, seminars, and continuous training (R1, R15, R14).	learning model training in various regions, especially to support more interactive and student-centered science learning.
Limited Resources and Infrastructure	R16, R17, R18, R21	Many schools in Indonesia have limited resources, such as laboratory facilities, teaching materials, and time for planning (R16, R17). This can make implementing the 4MAT learning model difficult, which requires additional resources.	The Merdeka Curriculum encourages using existing resources and creative approaches to learning. Implementing the 4MAT learning model can be adapted to the local context, for example, by using simple materials for science experiments or cost-effective integration of digital technologies.
Time Constraints and Implementation Complexity	R6, R10, R21	Implementing all phases of 4MAT takes a considerable amount of time, which can be an obstacle in dense class hours (R6, R10). The complexity of this model also demands detailed and thorough planning (R21).	The Merdeka Curriculum offers flexibility in lesson planning, allowing teachers to adjust the duration and steps of the 4MAT to suit the class's needs. Thus, teachers can choose the most relevant phase and integrate 4MAT more concisely.
Student Readiness and Learning Style Differences	R4, R13, R17, R20	4MAT requires teachers to present learning that suits four different learning styles, which can be challenging in the classroom with diverse learning styles and student needs (R4, R13). Some students also take longer to adapt to this approach (R17, R20).	The Merdeka Curriculum emphasizes differentiated and inclusive learning, enabling teachers to adapt the 4MAT strategy better to suit the needs of students in the classroom. These opportunities can be used to encourage student-centered learning and consider the diversity of students' learning styles.
Complex Evaluation and Assessment	R15, R17, R18, R21	Measuring student learning outcomes with the 4MAT learning model can be complicated because it involves aspects of creativity, attention, and conceptual understanding that are difficult to measure with traditional assessment methods (R15, R17, R18).	The Merdeka Curriculum provides space for formative and authentic assessments, making for more flexible and comprehensive evaluations. Assessments can include student portfolios, projects, and presentations to accommodate assessments based on the 4MAT learning model.
Limitations of Topics and Curriculum Alignment	R13, R19, R20	The 4MAT learning model requires adjusting the curriculum to be more suitable for certain topics, which can be challenging if the topics are not aligned with these methods (R13, R19). A rigid curriculum can limit the flexibility of applying this model (R20).	The Merdeka curriculum is designed to be flexible and adaptive, allowing teachers to adjust and integrate the 4MAT learning model into various science subjects. The curriculum also makes the development of projects relevant to real-life and project-based teaching, which is suitable for the 4MAT approach.

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The intensive training requirements for teachers underline a significant challenge in effectively implementing the 4MAT learning model. Studies R1, R14, and R15 indicate that teachers often struggle with mastering and applying the model optimally without comprehensive training. The complexity of designing lessons tailored to diverse student learning styles further underscores this challenge. However, the Merdeka Curriculum provides opportunities through initiatives such as the Guru Penggerak program and ongoing professional development, offering potential pathways for disseminating the 4MAT approach more broadly across regions.

Resource constraints, including inadequate laboratory facilities, limited learning materials, and insufficient time for lesson planning, present barriers, particularly in remote schools. Studies R16, R17, R18, and R21 suggest these factors significantly impact the effectiveness of the 4MAT model, which often requires additional resources and infrastructure. Nevertheless, the Merdeka Curriculum encourages teachers to adopt resourceful and creative teaching practices, such as utilizing low-cost, accessible materials and cost-effective digital tools, allowing strategic adaptation of the 4MAT model despite these limitations.

The complexity and extensive time demands inherent in the multi-phase structure of the 4MAT learning model create challenges for teachers working within limited instructional periods. Studies R6, R10, and R21 reveal the necessity for meticulous lesson planning to navigate these time constraints effectively. Nonetheless, the Merdeka Curriculum offers instructional flexibility, empowering educators to prioritize essential phases of the 4MAT model and tailor its implementation to fit available class hours better, enhancing practical applicability.

The diversity of student learning styles presents challenges in implementing the 4MAT learning model, as accommodating individual student needs requires tailored instructional strategies. According to studies R4, R13, R17, and R20, students' varying adaptation speeds to the model add complexity to classroom implementation. The Merdeka Curriculum, emphasizing differentiated and inclusive education, enables teachers to customize instructional strategies within the 4MAT framework better, optimizing its effectiveness in diverse classroom contexts.

Assessing student learning outcomes within the 4MAT learning model is challenging due to the complexity of evaluating creativity, engagement, and deeper conceptual understanding. Studies R15, R17, R18, and R21 highlight difficulties associated with traditional assessment methods, advocating for more flexible, formative, and authentic evaluation techniques. Merdeka Curriculum addresses this by facilitating alternative assessment forms, such as portfolios, projects, and presentations, thus effectively capturing critical thinking and creative skills integral to the 4MAT approach.

Effective integration of the 4MAT model necessitates curricular adjustments, as rigid curricular structures can restrict its implementation. Studies R13, R19, and R20 suggest that curriculum inflexibility poses challenges for the practical adoption of the 4MAT model. However, the adaptable and flexible design of the Merdeka Curriculum aligns closely with the experiential and exploratory principles of 4MAT, encouraging educators to implement this model in various science subjects with real-world relevance.

Despite implementation barriers, the flexibility of the Merdeka Curriculum provides a promising context for the effective adaptation of the 4MAT learning model. Through targeted teacher training, strategic resource use, flexible instructional planning, differentiated teaching strategies, authentic assessment methods, and curricular adaptability, educators can successfully overcome these challenges and optimize the benefits of the 4MAT model.

Discussion

This study aimed to examine research trends and analyze the impact and opportunities of the 4MAT instructional model within science education, specifically in the Indonesian curriculum context. The study emphasizes the significance of employing instructional models that cater to diverse learning styles, enhance student engagement, and foster critical thinking skills, closely aligning with the educational objectives set forth by Indonesia's current curriculum framework.

Research Trends and Practical Implications

The findings indicate that academic interest in the 4MAT instructional model peaked in 2020, significantly increasing scholarly publications across various databases. This surge likely correlates

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with global educational shifts and policy encouragement of innovative instructional practices, reflecting a response to rapidly evolving pedagogical needs during that period. Although the volume of publications declined slightly after 2022, consistent higher rates of publications in open-access platforms like Google Scholar underline researchers' continued engagement with accessible, widely disseminated knowledge resources. The sustained academic attention underscores the ongoing practical relevance of the 4MAT instructional model, suggesting its potential integration with emerging educational methodologies, such as blended or hybrid learning models, to address contemporary educational challenges.

The bibliometric analysis identified 298 conceptual links with a cumulative link strength of 1,534, highlighting the intricate interconnectedness in implementing the 4MAT model. These connections align closely with multidimensional teaching theories, emphasizing relationships between instructional strategies, student motivation, differentiated learning styles, and activity-based learning methods. Particularly notable is the substantial link strength (174) within science education, affirming the model's comprehensive impact across cognitive, affective, and psychomotor domains, as proposed by experiential learning frameworks. These strong conceptual connections provide practical guidance for educators seeking effective pedagogical frameworks adaptable to the Indonesian curriculum context.

Impact, Opportunities, and Future Directions for the 4MAT Learning Model in Indonesian Mathematics and Science Education

This study confirms the significant impact of the 4MAT instructional model in mathematics and science education within Indonesia, corroborating prior research that highlights its effectiveness in addressing diverse student learning styles and cultivating essential 21st-century competencies such as critical thinking and creativity. These outcomes align well with global educational movements advocating student-centered, active learning methodologies and closely match the objectives of the Profil Pelajar Pancasila.

Nonetheless, the study also highlights persistent challenges consistent with previous literature, notably teacher readiness, resource limitations, and curriculum alignment. Effective implementation of the 4MAT model demands considerable professional training and resource allocation, both unevenly distributed, particularly in remote regions. Addressing these issues practically involves targeted interventions such as specialized professional development programs, integration of digital technologies for equitable resource distribution, and enhanced curricular flexibility to accommodate varied instructional models.

The study's implications emphasize the necessity of systemic improvements, including robust teacher training initiatives, digital resource enhancement, and strategic curriculum adaptations. Moving forward, Indonesia should prioritize longitudinal research that examines the long-term impacts of the 4MAT model on student learning outcomes and evaluates effective strategies for overcoming regional resource disparities. Critical research gaps remain in understanding optimal conditions for sustained and scalable application of 4MAT, particularly regarding its adaptability in diverse regional contexts. Practically, the next steps should include developing standardized yet flexible teacher-training modules, leveraging accessible digital tools to bridge educational resource gaps, and establishing adaptable instructional frameworks. These forward-looking insights will facilitate the practical integration and sustained effectiveness of the 4MAT instructional model across varied educational landscapes in Indonesia.

Recommendation

Research trends on the 4MAT learning model demonstrate a strong connection with science education. Motivation, learning styles, instructional methods, and practical science applications are significantly interrelated, emphasizing their importance in enhancing science education quality. The holistic and multidimensional nature of the 4MAT model requires a synergistic approach, integrating various educational dimensions to support student learning outcomes effectively.

Policy Recommendations:

- Encourage systemic integration of the 4MAT instructional model into national education policy, specifically aligned with the Merdeka Curriculum framework.

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- Facilitate flexible curriculum guidelines to accommodate diverse instructional models such as 4MAT, enabling better responsiveness to educational needs across different regions.

Curriculum Design:

- Leverage the inherent flexibility of the Merdeka Curriculum to implement the 4MAT model effectively, promoting inclusive, student-centered, and contextualized learning environments.
- Design curricula that explicitly incorporate multidimensional teaching methods to enhance student motivation, engagement, and deeper conceptual understanding.

Teacher Development:

- Develop comprehensive, ongoing professional development programs targeting teacher competencies, effectively employing the 4MAT model.
- Provide training resources and instructional modules that address both theoretical and practical dimensions of the 4MAT instructional approach.
- Promote digital literacy and technological integration in teacher training programs to address resource limitations and facilitate innovative instructional practices.

Future Research Recommendations:

- Conduct longitudinal studies assessing the sustained impact of the 4MAT model on student learning outcomes across diverse Indonesian school contexts, comparing rural and urban settings.
- Investigate effective methods for overcoming challenges associated with resource constraints, teacher preparedness, and assessment complexity within the context of 4MAT implementation.
- Explore scalability factors and adaptive strategies for widespread, equitable implementation of the 4MAT instructional model.

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