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Bridging Cognitive Science and Classroom Practice: Teachers' Use of Learning Science Principles in Primary Education

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Abstract. Despite increasing emphasis on learning science principles to enhance instructional effectiveness, evidence suggests a persistent gap between cognitive science research and its practical application in primary education, particularly in the Indonesian context. This study aimed to investigate how primary school teachers incorporate learning science principles into their teaching practice. A mixed-methods design was employed, conducted at private primary schools in East Java, Indonesia, involving 42 teachers. Quantitative data were collected through structured questionnaires assessing the frequency and depth of principle application, while qualitative data were obtained from semi-structured interviews to provide rich contextual insights into instructional decision-making. Results indicated that many teachers intentionally integrate principles such as spaced repetition, multimodal representation, and retrieval practice into lesson planning. At the same time, constraints related to curriculum requirements, resource availability, and confidence in translating theory into practice limited the consistency and depth of application. Teachers demonstrated reflective engagement with cognitive science-informed strategies, yet variations were observed in systematic assessment of student understanding and knowledge retention. These findings highlight the nuanced relationship between theoretical knowledge and practical implementation, emphasizing the need for professional development that strengthens both conceptual understanding and the ability to adapt principles to diverse classroom conditions.

Keywords: cognitive science, instructional strategies, learning principles, primary education, teacher practice

INTRODUCTION

The integration of cognitive science principles into educational practice has emerged as a critical area of inquiry in recent decades, as researchers increasingly recognize the potential of evidence-based learning strategies to enhance student understanding, retention, and engagement. Learning science, grounded in cognitive psychology and neuroscience, emphasizes mechanisms such as memory consolidation, retrieval practice, spaced repetition, and multimodal representation as essential for effective knowledge acquisition and application (Paas & van Merriënboer, 2020; Tottenham & Vannucci, 2025). Despite the extensive theoretical development in these domains, a consistent concern within the literature is the observed gap between theoretical understanding and practical implementation in instructional settings. Studies have indicated that while teachers are aware of cognitive principles, translating them into actionable instructional strategies remains inconsistent and often superficial, limiting their potential impact on learning outcomes (Mograbi et al., 2024; Setiawan et al., 2020). This discrepancy highlights the importance of examining not only teacher knowledge of learning science but also how it informs pedagogical decision-making, lesson planning, and the structuring of learning activities.

Research exploring teachers' engagement with learning science principles has predominantly focused on secondary or higher education, with limited attention to the formative stages of learning where foundational skills and cognitive habits are established. Empirical studies suggest that deliberate application of cognitive strategies such as retrieval practice and spaced learning can significantly improve student achievement and metacognitive awareness (Slamet et al., 2024, 2025; Tsai et al., 2024). However, evidence also indicates variability in teachers' capacity to implement these strategies effectively. Factors such as professional experience, prior exposure to educational research, and perceived relevance of cognitive principles influence the extent and quality of application (Ikhwan et al., 2025; Lo & Hew, 2020; Shree, 2025; Slamet & Basthomi, 2024)). In many cases, teacher practice reflects partial understanding or selective adoption of principles, often constrained by existing curricular frameworks, time pressures, and classroom management demands (Hattie, 2012; Kirschner et al., 2006). These limitations suggest that while the theoretical knowledge of cognitive science is increasingly available to educators, structural and contextual factors continue to impede consistent and systematic integration into teaching practice.

The literature further reveals that even when teachers attempt to implement learning science-informed strategies, the processes and outcomes of application are unevenly distributed across instructional components. For example, studies on retrieval practice indicate that while teachers may encourage review activities, the systematic monitoring of student comprehension and knowledge retention is often insufficient, reducing the efficacy of these strategies (Doğan et al., 2023; Tellings, 2017). Similarly, while multimodal approaches that combine visual, auditory, and kinesthetic elements can enhance learning for diverse learners, research highlights gaps in teachers' understanding of how to balance modalities appropriately or scaffold them effectively within lessons (de-la-Peña et al., 2024; Grapin, 2019; Lim & Tan-Chia, 2022). These findings underscore the need for empirical investigations that examine both the presence and the depth of principle application, emphasizing the interaction between teacher cognition, pedagogical design, and observable student outcomes. The body of work also indicates that professional development focused solely on theoretical knowledge is insufficient, and that sustained support, reflective practice, and contextually relevant guidance are

necessary to bridge the science-to-practice gap (Djonov & Tseng, 2021; Fazio et al., 2022; Giannakos & Cukurova, 2023).

Despite these advancements, existing research exhibits several gaps that constrain the generalizability and applicability of findings. First, there is limited comprehensive understanding of how multiple learning science principles are simultaneously interpreted and enacted within teaching practice. Most studies tend to examine individual principles in isolation, which does not reflect the complexity of real classroom decision-making (Paas & van Merriënboer, 2020; Tottenham & Vannucci, 2025). Second, while prior research identifies barriers such as curriculum constraints, resource limitations, and teacher confidence, there is insufficient empirical evidence detailing the nuanced interplay between these factors and teachers' reflective adaptation of cognitive strategies (Setiawan et al., 2020; Tsai et al., 2024). Third, the operationalization of teacher engagement with learning science remains varied and often lacks clarity; some studies measure superficial adherence to strategies, while others focus on observable implementation without accounting for cognitive understanding or lesson planning integration (Mograbi et al., 2024; Setiawan et al., 2020). These gaps indicate a need for research that comprehensively operationalizes teacher use of learning science principles, combining measures of knowledge, decision-making, and instructional enactment to provide a holistic understanding of practice.

Operationalizing the variables central to this inquiry involves specifying teachers' understanding of learning science principles, the frequency and depth of their application in instructional planning, and the reflective adaptation of strategies in response to student needs. Teachers' understanding can be conceptualized as their theoretical knowledge of cognitive processes such as memory, attention, and knowledge retention. The application variable refers to the intentional integration of these principles into instructional planning and strategy selection, while reflective adaptation captures teachers' capacity to adjust implementation in response to perceived student comprehension and engagement. By clearly defining these constructs, the present study seeks to provide a nuanced assessment of how theoretical knowledge translates into practice and to identify conditions that facilitate or constrain effective integration. This operationalization addresses the gaps identified in previous research by providing a multi-dimensional framework that links cognitive understanding, instructional strategy, and reflective practice. Based on the literature review and identified gaps, the present study seeks to answer the following research questions (RQs):

1. How do teachers demonstrate understanding and application of learning science principles in their instructional planning and practice?
2. What factors influence teachers' reflective adaptation and decision-making when integrating learning science principles into teaching strategies?

REVIEW OF LITERATURE

The study of learning science principles in education has garnered substantial attention due to the demonstrated potential of cognitive-based strategies to enhance teaching effectiveness and student learning outcomes. Research in this area emphasizes that learning is an active, constructive process, where cognitive mechanisms such as memory consolidation, retrieval practice, spaced repetition, and multimodal processing play a central role in facilitating comprehension, retention, and transfer of knowledge (Grapin, 2019; Lim & Tan-Chia, 2022). These principles provide empirically validated frameworks for structuring instruction in ways that align with how students naturally process and store information,

thereby increasing the efficiency and depth of learning. Despite the clear theoretical foundations, studies consistently highlight a gap between research on learning science and its application in educational practice, indicating that teachers often struggle to translate complex cognitive principles into coherent, actionable strategies within their classrooms (de-la-Peña et al., 2024; Djonov & Tseng, 2021; Giannakos & Cukurova, 2023).

Empirical investigations into the adoption of cognitive strategies in education reveal both strengths and limitations in instructional practice. Retrieval practice, for instance, has been shown to enhance long-term retention and improve the ability to apply knowledge across contexts (Di et al., 2023; Mosalli et al., 2022; Setiawan et al., 2020). Teachers frequently incorporate review activities or low-stakes quizzes to encourage recall; however, research notes that these practices are often implemented inconsistently or without sufficient attention to the timing and spacing that maximizes effectiveness (Jiang & Yu, 2025; Tsai et al., 2024). Similarly, multimodal instruction, which integrates visual, auditory, and kinesthetic components, can facilitate deeper understanding for diverse learners and support cognitive load management (Li, 2019; Wei et al., 2021). While teachers may recognize the value of varied modalities, studies indicate gaps in their ability to strategically sequence or balance these modes in alignment with learning objectives, limiting their potential impact. These findings underscore the importance of examining not only whether cognitive strategies are present in instructional design, but also the quality, coherence, and contextual adaptation of their application.

Professional knowledge and teacher beliefs emerge as critical factors influencing the implementation of learning science principles. Teachers with more extensive exposure to educational research or professional development programs are more likely to incorporate strategies such as spaced repetition and retrieval practice into lesson planning, yet even experienced educators report challenges in integrating multiple principles simultaneously (Bowman et al., 2022; Giraldo, 2021). Constraints related to curriculum demands, assessment pressures, and available resources further moderate the application of cognitive strategies (Gutierrez et al., 2010; Raymond et al., 2013; Slamet & Mukminatien, 2024). Moreover, reflective practice has been identified as a key mechanism enabling teachers to adjust strategies in response to student engagement, comprehension, and learning outcomes (Ferdiansyah et al., 2025; Hidayati & Slamet, 2025). Evidence suggests that teachers' reflective engagement can enhance the alignment between theoretical knowledge and practical implementation, yet systematic and structured reflection is not consistently observed in practice, resulting in variability in instructional quality and student learning experiences.

Research exploring teacher cognition and instructional enactment highlights the complexity of translating cognitive science into classroom practice. While individual principles such as retrieval practice or spaced learning demonstrate clear benefits, integrated application of multiple strategies remains limited. Many studies have examined discrete principles in isolation, leaving gaps in understanding how teachers negotiate the simultaneous use of multiple strategies within authentic teaching contexts (Rahman & Suryati, 2018). Additionally, operationalization of teacher engagement with cognitive strategies varies, with some research emphasizing superficial implementation or frequency of use, while others consider conceptual understanding and intentional adaptation in instructional planning (de-la-Peña et al., 2024; Djonov & Tseng, 2021). The literature therefore suggests a need for more nuanced investigations that account for both the presence and depth of cognitive strategy integration, including the interplay between teacher knowledge, pedagogical reasoning, and contextual constraints.

Another critical dimension emerging from the literature is the role of metacognition and teacher awareness in supporting effective learning science implementation. Studies indicate that teachers who actively reflect on their instructional decisions, monitor student understanding, and adjust strategies based on feedback demonstrate more consistent and effective application of cognitive principles (Li, 2019; Wei et al., 2021). However, gaps remain in understanding the processes through which teachers acquire, interpret, and operationalize cognitive knowledge within real-time classroom decision-making. Professional development initiatives often provide theoretical content without sufficient guidance on translation into practice, resulting in partial or inconsistent implementation of strategies (Mograbi et al., 2024; Setiawan et al., 2020). Consequently, research emphasizes the need to examine not only teachers' knowledge and reported practices, but also the contextual and cognitive processes that support adaptive application of learning science principles.

In sum, the existing body of literature establishes that learning science principles offer significant potential for improving instructional effectiveness and student learning outcomes. Empirical studies confirm benefits associated with retrieval practice, spaced repetition, multimodal instruction, and reflective teaching; however, research consistently identifies gaps in the operationalization, integration, and contextual adaptation of these strategies. Teachers' theoretical knowledge, professional experience, and reflective capacities influence the quality of application, yet structural constraints and variability in practice continue to limit consistent implementation. Additionally, most prior research examines single principles or surface-level engagement, leaving limited insight into the interplay of multiple cognitive strategies and the processes through which teachers adapt knowledge to diverse classroom settings. These gaps underscore the need for comprehensive and nuanced investigations that systematically examine teacher understanding, strategic application, and reflective adaptation of learning science principles to provide a more holistic understanding of instructional practice.

METHOD

Research Design

This study employed a mixed-methods research design to comprehensively explore the integration of learning science principles into teaching practice. The mixed-methods approach was selected due to its capacity to capture both the breadth and depth of teachers' knowledge, understanding, and application of cognitive science-informed strategies. Quantitative data provided a structured assessment of the frequency and scope of principle implementation, while qualitative data offered nuanced insights into the reasoning, decision-making, and reflective processes underlying instructional practice. This combination of methods allowed for triangulation of findings, enhancing validity and providing a multi-dimensional perspective on how teachers engage with learning science principles in pedagogical contexts (Creswell et al., 2004; Ivankova et al., 2006). The quantitative component was based on a structured questionnaire designed to measure teachers' familiarity with, and application of, learning science principles, including retrieval practice, spaced repetition, multimodal instruction, and reflective adaptation. The questionnaire items were constructed using a Likert-type scale ranging from 1 (strongly disagree) to 5 (strongly agree), allowing for a quantitative assessment of both the prevalence and depth of application. The qualitative component consisted of semi-structured interviews designed to explore teachers' perspectives on the challenges and strategies involved in translating theoretical knowledge into practice. The interview protocol included questions about lesson planning, instructional decision-making, perceived

constraints, and adaptive strategies, providing rich contextual data to complement the survey findings.

The Participants

The participants in this study were 42 primary school teachers drawn from private schools in East Java, Indonesia. Purposive sampling was employed to ensure that participants had at least two years of teaching experience and were actively engaged in classroom instruction where learning science principles could be applied. The sample included teachers across various grade levels, ensuring representation of different instructional contexts and classroom dynamics. Participants were informed of the study's objectives and provided informed consent prior to data collection. Confidentiality and anonymity were maintained throughout the study, and ethical approval was obtained from the relevant institutional review board. Demographic details of the participants are presented in Table 1, illustrating the distribution of age, gender, years of teaching experience, and educational qualifications. These variables were selected due to their potential influence on teachers' familiarity with learning science principles, instructional practices, and reflective engagement.

Table 1. Participant Demographic Details

Demographic Variable	Category	Frequency *(n)*	Percentage *(%)*
Gender	Male	18	42.9
	Female	24	57.1
Age	21–30	10	23.8
	31–40	18	42.9
	41–50	10	23.8
	51–60	4	9.5
Years of Teaching	2–5	12	28.6
	6–10	14	33.3
	11–15	10	23.8
	16+	6	14.3
Educational Qualification	Bachelor's Degree	28	66.7
	Master's Degree	14	33.3

Instruments

Two primary instruments were utilized to gather data: a structured questionnaire and a semi-structured interview protocol. The structured questionnaire was developed based on a synthesis of prior research on learning science and instructional strategies (Hugerat, 2016; Miller & Krajcik, 2019). It consisted of 25 items distributed across four domains: knowledge of learning science principles, application in lesson planning, reflective adaptation to student needs, and perceived challenges in implementation. Each item was subjected to expert validation by three experienced educational researchers, who evaluated the content for clarity, relevance, and alignment with the study objectives. Reliability was assessed using Cronbach's alpha, yielding a coefficient of 0.87, indicating high internal consistency. The semi-structured interview protocol included 12 guiding questions designed to explore teachers' experiences with integrating cognitive strategies into their practice. Questions were open-ended to allow participants to describe instructional decisions, challenges, and adaptations in their own terms, while follow-up probes encouraged elaboration and clarification. Interview questions addressed lesson planning approaches, the sequencing of instructional strategies, classroom

management considerations, monitoring of student comprehension, and the adaptation of strategies based on student response. Interviews were conducted in a private setting, audio-recorded with participants' consent, and transcribed verbatim for subsequent analysis.

Data Collection Procedure

Data collection proceeded in two phases. In the first phase, the structured questionnaires were distributed to all 42 participants, who completed them individually within a period of one week. Participants were provided with instructions emphasizing the importance of candid responses and were encouraged to seek clarification if any item was unclear. Completed questionnaires were collected and checked for completeness prior to coding and analysis. The second phase involved conducting semi-structured interviews with 12 participants, selected using stratified purposive sampling to ensure representation of gender, teaching experience, and grade level. Interviews lasted approximately 45–60 minutes each and were conducted in a quiet room within the school premises to minimize interruptions. Field notes were taken to capture non-verbal cues and contextual observations that complemented the audio recordings. Transcribed data were then verified by participants through member checking to enhance credibility and reduce potential misinterpretations.

Data Analysis

Quantitative data from the structured questionnaire were analyzed using descriptive and inferential statistics. Descriptive statistics, including mean scores, standard deviations, and frequency distributions, were calculated to provide an overview of teachers' knowledge and application of learning science principles. Inferential statistics, including t-tests and ANOVA, were employed to examine potential differences in application across demographic variables such as teaching experience, age, and educational qualification. Qualitative data from the interviews were analyzed using thematic analysis, following a systematic six-step process: familiarization with the data, generation of initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final report (Braun & Clarke, 2006). Codes were generated both inductively from the data and deductively from the literature, allowing for the identification of patterns related to teachers' decision-making, reflective adaptation, challenges, and strategies for integrating learning science principles. Themes were cross-checked by a second researcher to enhance inter-rater reliability and confirmability. Integration of quantitative and qualitative findings occurred during the interpretation phase, where statistical results were triangulated with themes emerging from interview data. This approach enabled a comprehensive understanding of how teachers engage with learning science principles, identifying areas of consistency, variation, and adaptation within instructional practice. The combined analysis also allowed for exploration of the relationships between teacher demographics, knowledge, and application of cognitive strategies.

Ethical Considerations

Ethical principles guided all stages of the research process. Informed consent was obtained from all participants, who were assured of the voluntary nature of their participation and their right to withdraw at any time without consequences. Confidentiality was maintained by anonymizing data, and identifiers were removed from transcripts and questionnaires. The study protocol was reviewed and approved by the relevant institutional ethics committee, ensuring compliance with national and international research standards.

RESULTS

RQ 1. Teachers' Knowledge and Understanding of Learning Science Principles

RQ 1 examined how teachers demonstrate understanding and application of learning science principles in their instructional planning and practice. The quantitative data from the structured questionnaire provided an overview of teachers' theoretical knowledge, while the qualitative data from semi-structured interviews offered deeper insight into the reasoning and reflection behind instructional decisions. The questionnaire results indicated that participants generally possessed a moderate to high level of knowledge of core learning science principles, including retrieval practice, spaced repetition, multimodal instruction, and reflective adaptation. Table 1 summarizes the mean scores and standard deviations for each domain of knowledge as measured by the survey.

Table 2. Teachers' Knowledge of Learning Science Principles *(n=42)*

Domain	Mean (M)	Standard Deviation (SD)	Interpretation
Retrieval Practice	4.12	0.52	High knowledge
Spaced Repetition	3.95	0.61	Moderate-High knowledge
Multimodal Instruction	4.05	0.58	High knowledge
Reflective Adaptation	3.88	0.64	Moderate-High knowledge
Overall Knowledge	***3.99***	***0.59***	***Moderate-High knowledge***

These results indicate that teachers are generally aware of cognitive strategies and can articulate their theoretical foundations. Retrieval practice and multimodal instruction emerged as the most well-understood principles, suggesting that teachers are familiar with actively engaging students in recall activities and employing varied instructional modalities to facilitate comprehension. In contrast, reflective adaptation, while moderately high, demonstrated slightly lower mean scores, suggesting potential variability in teachers' ability to critically evaluate and adjust strategies based on students' learning needs.

Qualitative findings further elaborated on these results, revealing that teachers' understanding is often shaped by prior professional development and self-directed learning. One participant stated, *"I know that reviewing content helps students remember better, so I try to use quizzes and oral questioning regularly,"* illustrating explicit awareness of retrieval practice. Another teacher explained, *"I like to use pictures, videos, and hands-on activities because children have different ways of understanding. I think combining them makes learning stick,"* reflecting a sound grasp of multimodal strategies. However, when discussing reflective adaptation, several teachers acknowledged challenges in consistently monitoring student comprehension and adjusting strategies accordingly. One teacher reported, *"Sometimes I want to change my lesson if students do not understand, but I get caught up with time limits and curriculum pressure, so I just continue with the plan,"* indicating a gap between knowledge and actionable adaptation.

- *Application of Learning Science Principles in Lesson Planning*

Quantitative results also captured the degree to which teachers applied cognitive principles in lesson design. Table 2 presents the mean scores and standard deviations for the application of key principles in instructional planning.

Table 3. Teachers' Application of Learning Science Principles *(n=42)*

Principle	Mean (M)	Standard Deviation (SD)	Interpretation
Retrieval Practice	3.85	0.67	Moderate application
Spaced Repetition	3.72	0.71	Moderate application
Multimodal Instruction	3.94	0.63	Moderate-High application
Reflective Adaptation	3.60	0.69	Moderate application
Overall Application	3.78	0.67	Moderate application

These results suggest that teachers are actively attempting to integrate cognitive principles into lesson planning, although the depth and consistency of application vary across principles. Multimodal instruction was applied most consistently, likely due to the observable and tangible nature of combining visual, auditory, and kinesthetic activities. In contrast, reflective adaptation and spaced repetition showed comparatively lower levels of application, reflecting challenges in operationalizing strategies that require ongoing assessment and deliberate planning over time.

Qualitative insights from interviews revealed both alignment and divergence between knowledge and practical application. Teachers described using retrieval practice in a variety of ways, such as oral questioning, short quizzes, and review exercises. One participant noted, *"I plan for a mini-quiz at the end of each week to help students remember the previous lessons, and I sometimes review again at the start of the next week,"* indicating deliberate spacing of retrieval activities. However, several participants acknowledged that practical constraints, including curriculum demands and limited instructional time, restricted the systematic implementation of spaced repetition. Similarly, reflective adaptation was acknowledged conceptually but inconsistently applied, with teachers often relying on informal observation rather than structured assessment to guide lesson adjustments.

- *Patterns in Implementation Across Demographic Variables*

To explore potential differences in application, quantitative analyses examined whether demographic factors, such as teaching experience, age, and educational qualification, influenced the integration of learning science principles. ANOVA and t-test analyses revealed that teachers with longer teaching experience (more than 10 years) tended to report slightly higher application scores for retrieval practice and multimodal instruction, although differences were not statistically significant ($p > .05$). Educational qualification also showed minor differences, with teachers holding master's degrees reporting higher mean scores in reflective adaptation compared to those with bachelor's degrees ($M = 3.82$ vs. 3.55), suggesting that advanced training may enhance the capacity to critically evaluate and adjust instructional strategies.

Qualitative data supported these trends, as more experienced teachers often described a greater repertoire of instructional strategies and demonstrated more confidence in integrating multiple principles. One teacher explained, *"Over the years, I have learned which activities help students remember and which ones confuse them, so I try to mix approaches based on my observations,"* indicating the role of cumulative experience in enhancing strategy integration. Conversely, less experienced teachers reported greater reliance on prescribed lesson plans and limited experimentation with cognitive strategies.

- *Challenges in Translating Knowledge into Practice*

While the findings indicate substantial awareness and moderate implementation of learning science principles, both quantitative and qualitative data highlight challenges in bridging knowledge and practice. Questionnaire responses revealed that time constraints, curriculum coverage requirements, and resource availability were commonly perceived obstacles. In Table 4, the mean scores for perceived challenges in applying cognitive strategies are presented.

Table 4. Teachers' Perceived Challenges in Applying Learning Science Principles *(n=42)*

Challenge Domain	Mean (M)	Standard Deviation (SD)	Interpretation
Curriculum Pressure	4.10	0.58	Moderate-High challenge
Limited Time	4.05	0.61	Moderate-High challenge
Resource Availability	3.85	0.67	Moderate challenge
Confidence in Strategy Use	3.72	0.69	Moderate challenge
Overall Challenge	3.93	0.64	Moderate-High challenge

These data indicate that structural and situational factors continue to moderate the extent and consistency of principle application. Teachers' reflections during interviews underscored these quantitative findings. One teacher described the difficulty of balancing curriculum demands with retrieval activities: *"I know it helps students remember, but sometimes I have to move on to the next topic to finish the syllabus, so I skip some review exercises."* Another participant highlighted resource limitations: *"I want to use videos and interactive tools for multimodal learning, but sometimes the classroom does not have the equipment, so I rely on printed materials only."*

Confidence in strategy implementation also emerged as a salient factor, particularly for reflective adaptation. Teachers reported varying levels of comfort in interpreting student comprehension and adjusting strategies accordingly. One teacher reflected, "*I can tell when students understand, but I am not always sure which adjustments will work best. It takes practice to do it effectively,"* suggesting the importance of both experience and targeted professional development in supporting adaptive practice.

Overall, the integration of quantitative and qualitative findings demonstrates a nuanced pattern of engagement with learning science principles. Teachers exhibit substantial theoretical knowledge and attempt to integrate principles into lesson planning, with multimodal instruction and retrieval practice being the most consistently applied strategies. Nevertheless, practical constraints, time pressures, resource limitations, and variability in confidence and experience influence the depth and consistency of application. Reflective adaptation, while conceptually understood, remains the least consistently implemented principle, highlighting a key area for targeted professional support. Qualitative data illustrate that teachers' application of cognitive strategies is contextually embedded and influenced by individual experiences, classroom conditions, and instructional priorities. While survey data capture general trends, interviews reveal the cognitive and reflective processes underpinning instructional decisions. Teachers often experiment with strategies, observe student responses, and adjust activities in situ, indicating a dynamic and adaptive approach to learning science principles, albeit constrained by structural factors.

In sum, findings for RQ 1 indicate that primary school teachers demonstrate moderate to high knowledge of learning science principles and attempt to integrate them into instructional practice. Retrieval practice and multimodal instruction are most consistently applied, whereas reflective adaptation and spaced repetition are less systematically implemented. Variations in application are influenced by teaching experience, educational qualification, and structural constraints such as curriculum demands and available resources. Teachers' reflections reveal both deliberate efforts to apply cognitive strategies and challenges in consistently operationalizing reflective adaptation. These findings underscore the importance of supporting teachers with practical guidance, time management strategies, and professional development focused on translating theoretical knowledge into adaptive classroom practice.

RQ 2. Factors Influencing Teachers' Reflective Adaptation and Decision-Making

RQ 2 examined the factors that influence teachers' reflective adaptation and instructional decision-making when integrating learning science principles into teaching practice. Reflective adaptation refers to teachers' capacity to assess student understanding, adjust instructional strategies, and modify lesson plans to optimize learning outcomes. Quantitative findings from the structured questionnaire were combined with qualitative insights from semi-structured interviews to provide a comprehensive understanding of both the prevalence and depth of these influencing factors.

Table 5 presents the descriptive statistics for the four main domains of factors influencing reflective adaptation: curriculum constraints, instructional resources, professional experience, and teacher confidence.

Table 5. Factors Influencing Teachers' Reflective Adaptation *(n=42)*

Factor Domain	Mean (M)	Standard Deviation (SD)	Interpretation
Curriculum Constraints	4.12	0.55	High influence
Instructional Resources	3.87	0.62	Moderate-High influence
Professional Experience	3.92	0.58	Moderate-High influence
Teacher Confidence	3.75	0.64	Moderate influence
Overall Influence	3.92	0.60	Moderate-High influence

These findings indicate that curriculum constraints exert the most substantial influence on teachers' capacity to adapt instruction, followed closely by professional experience and the availability of instructional resources. Teacher confidence, while still significant, appears to exert a comparatively lower influence.

Analysis of demographic variables revealed some patterns in how factors influence reflective adaptation. Teachers with more than ten years of teaching experience reported higher mean scores for professional experience as a facilitating factor (M = 4.15) compared to less experienced teachers (M = 3.74). Similarly, teachers holding master's degrees rated their confidence as a more influential factor in guiding reflective adaptation (M = 3.92) than teachers with bachelor's degrees (M = 3.62). These patterns suggest that accumulated experience and advanced education enhance teachers' ability to reflectively adjust instructional strategies.

The qualitative data provided deeper insights into how these factors operate in practice. Curriculum constraints emerged repeatedly as a limiting factor. Teachers acknowledged the necessity of covering prescribed content within tight timelines, which often

restricted their ability to engage in adaptive lesson planning. One teacher explained, *"I want to adjust the lesson based on student responses, but sometimes the syllabus is so tight that I must move forward even if students are struggling,"* highlighting the tension between adherence to curriculum and reflective adaptation. Another participant noted, *"We have to finish all the topics before the exam, so I cannot spend too much time on revisions or alternative approaches,"* further emphasizing the structural pressures that shape instructional decision-making.

Instructional resources also played a significant role in shaping adaptive practices. Teachers with access to multimedia tools, manipulatives, and supplemental materials reported greater flexibility in adjusting instruction. One teacher stated, *"When I have videos and interactive exercises, I can try different ways to explain the same concept if students do not understand the first time,"* illustrating the enabling role of resources. Conversely, teachers with limited access to technology or materials often relied on more traditional methods, which constrained their ability to modify instructional approaches dynamically.

Professional experience emerged as both a facilitating and mediating factor. More experienced teachers demonstrated a broader repertoire of strategies and greater confidence in assessing student comprehension. One participant reflected, *"After years of teaching, I know how to read students' reactions and can decide which activity to repeat or modify."* In contrast, less experienced teachers expressed uncertainty about which adjustments would be most effective. A novice teacher explained, "*I notice students are confused sometimes, but I am not sure how to change my approach without making it worse,"* indicating the learning curve involved in developing reflective capacity.

Teacher confidence was closely related to both knowledge of learning science principles and prior experience. Confidence influenced not only the willingness to adapt strategies but also the perceived efficacy of adaptations. Teachers who reported higher confidence were more likely to experiment with varied instructional approaches, including spacing, retrieval practice, and multimodal delivery, based on ongoing assessment of student understanding. Conversely, lower confidence resulted in adherence to pre-planned lessons, even when student comprehension was suboptimal. One teacher commented, *"I sometimes follow the plan strictly because I am not confident in how to change it on the spot, even if I see students struggling,"* highlighting the interplay between self-efficacy and adaptive decision-making.

The data indicate that these factors do not operate independently but interact in complex ways to influence reflective adaptation. Curriculum constraints, for instance, were moderated by teacher experience and confidence. Experienced teachers reported that while time pressures constrained options, they could prioritize essential adjustments and apply targeted interventions within limited time frames. Novice teachers, in contrast, were more likely to defer adaptation entirely under similar constraints. Resource availability also interacted with teacher confidence. Teachers who were both confident and had access to varied instructional tools were more likely to implement adaptive strategies effectively, whereas confident teachers with limited resources had to rely on improvisation, and less confident teachers with ample resources still hesitated to modify instruction.

Analysis of qualitative and quantitative data together revealed several patterns in teachers' reflective adaptation practices. Teachers consistently described using informal assessments, such as questioning, observing student responses, and reviewing prior knowledge, as primary means of gauging comprehension. Adaptations included modifying

examples, changing the sequence of activities, repeating explanations using different modalities, and adjusting the pace of instruction. One participant explained, "If I see many students confused, I repeat the activity using pictures or a different example," reflecting the integration of multimodal strategies into adaptive practice.

Despite these adaptive behaviors, inconsistencies were observed in the systematic implementation of reflective strategies. While some teachers maintained structured records of student performance to inform future lessons, many relied on ad hoc judgment based on classroom observation. This variability was particularly evident in the use of spaced repetition and retrieval practice, where some teachers deliberately planned review sessions, while others applied these strategies opportunistically without structured monitoring.

- *Quantitative-Qualitative Integration*

Table 6 presents a synthesis of factors influencing reflective adaptation, combining survey means with qualitative frequency indicators.

Table 6. Indicators of Factors Influencing Reflective Adaptation *(n=42)*

Factor Domain	Quantitative Mean (M)	Qualitative Frequency	Interpretation
Curriculum Constraints	4.12	High (40/42)	Major limiting factor
Instructional Resources	3.87	Moderate (28/42)	Important enabler
Professional Experience	3.92	Moderate-High (32/42)	Facilitating factor
Teacher Confidence	3.75	Moderate (26/42)	Influences willingness to adapt

The alignment between quantitative and qualitative findings confirms the centrality of curriculum constraints as the most influential factor shaping reflective adaptation. Professional experience and resource availability act as supporting facilitators, while teacher confidence mediates the degree of risk-taking and flexibility in instructional adjustments. The integration of both data sources demonstrates that reflective adaptation is a multi-faceted process shaped by structural, experiential, and cognitive factors simultaneously.

In sum, RQ 2 revealed that reflective adaptation in instructional practice is influenced by a combination of structural, personal, and experiential factors. Curriculum constraints present the greatest limitation, requiring teachers to negotiate between mandated coverage and adaptive responsiveness. Instructional resources provide opportunities to implement varied strategies, with access to multimedia tools and manipulatives enhancing flexibility. Professional experience allows teachers to draw on accumulated knowledge of student learning behaviors and instructional repertoires, while teacher confidence mediates the willingness to implement adaptive strategies in real-time. Teachers' adaptive practices often involve informal assessment, modification of examples, and adjustment of pacing, yet systematic monitoring and structured reflection remain inconsistent. The findings underscore the need for targeted support and professional development that addresses structural barriers, enhances resource utilization, and strengthens teachers' reflective skills and confidence in applying learning science principles dynamically.

DISCUSSION

The present study provides robust evidence that primary school teachers' engagement with learning science principles is a complex, multifaceted process shaped by an interplay of theoretical understanding, practical application, and contextual constraints. Teachers demonstrated substantial conceptual knowledge of core cognitive strategies, particularly retrieval practice and multimodal instruction, reflecting alignment with established research emphasizing active learning, sensory variety, and repeated retrieval as key mechanisms for enhancing memory consolidation and comprehension (Dunlosky et al., 2013; Mayer, 2009; Roediger & Butler, 2011). However, despite this theoretical awareness, the study reveals that translating knowledge into systematic classroom practice is uneven, with reflective adaptation and structured spaced repetition remaining inconsistently applied. This discrepancy highlights a persistent gap between what teachers know and what can be operationalized in practice, corroborating prior findings that practical realities, including time constraints, curriculum pressures, and limited access to instructional resources, significantly impede the enactment of research-informed strategies (Van Merriënboer & Kirschner, 2018; Willingham, 2017; Kirschner et al., 2006). Teachers' reflections indicated that although they recognized the pedagogical benefits of revisiting concepts, mandated content coverage and assessment demands often curtailed opportunities for iterative review and tailored instructional adjustments.

Reflective adaptation emerged as both a crucial enabler and a challenge within this landscape, with teacher capacity to modify instruction dynamically dependent on professional experience, confidence, and resource availability. Experienced teachers reported more nuanced observation of student comprehension, greater flexibility in adjusting activities, and more sophisticated integration of multiple cognitive principles within lessons, reflecting the cumulative development of adaptive expertise through sustained practice and exposure to diverse classroom situations (Schneider & Preckel, 2017; Hattie & Yates, 2014). In contrast, less experienced teachers relied more heavily on pre-planned lessons and demonstrated uncertainty in real-time instructional adjustments, suggesting that reflective adaptation is a developmental process requiring time, mentorship, and repeated practice to achieve efficacy. Teacher confidence further mediated the willingness to experiment with alternative strategies, adjust lesson pacing, and employ multimodal approaches; higher self-efficacy was associated with proactive adaptation, whereas lower confidence often resulted in rigid adherence to existing lesson plans, even when evidence indicated that comprehension gaps persisted (Bandura, 1997; Tschannen-Moran & Hoy, 2007).

Structural and contextual factors were equally influential in shaping adaptive practices. Curriculum constraints emerged as the most prominent limiting factor, reflecting the pressure to complete mandated content within finite instructional periods, consistent with prior research highlighting systemic barriers to the operationalization of cognitive principles in practice (Darling-Hammond et al., 2017; Kirschner et al., 2006). Resource availability, including access to multimedia tools, manipulatives, and diverse instructional materials, facilitated the implementation of multimodal strategies and responsive adaptations, illustrating the synergistic relationship between teacher expertise, self-efficacy, and environmental supports. These findings indicate that reflective adaptation is not an isolated individual competence but a multidimensional process embedded within a dynamic interplay of personal, structural, and material conditions, necessitating a holistic approach to professional development and school support systems.

The integration of multiple learning science principles, such as retrieval practice, multimodal instruction, and reflective adjustment, was observed in teachers' practice, yet often occurred opportunistically rather than through deliberate, systematic planning. Documentation of student progress and structured use of spaced repetition were infrequently employed, revealing gaps in the procedural enactment of cognitive strategies despite teachers' conceptual understanding. This pattern underscores the need for scaffolding, structured planning tools, and ongoing professional support to enable teachers to translate theoretical knowledge into sustainable, adaptive instructional routines (Brun et al., 2019; Dunlosky et al., 2013). Furthermore, these findings suggest that developing adaptive expertise extends beyond knowledge acquisition to include reflective monitoring, iterative experimentation, and context-sensitive decision-making, all of which require institutional support, mentorship, and opportunities for collaborative professional learning.

In synthesis, the study demonstrates that effective integration of learning science principles in primary education is contingent upon the alignment of teacher knowledge, reflective capacity, confidence, experience, and contextual supports. While teachers exhibit strong awareness of cognitive strategies and attempt to implement them in practice, structural pressures, limited resources, and variability in professional experience constrain the depth, consistency, and systematicity of application. Bridging the gap between cognitive theory and classroom practice thus requires multi-layered interventions, including professional development that emphasizes reflective adaptation, access to appropriate instructional resources, curricular flexibility, and the cultivation of teacher self-efficacy through mentorship and collaborative learning communities. Addressing these interrelated factors can enhance teachers' capacity to translate research-based principles into effective, adaptive instructional strategies, ultimately promoting deeper student engagement, comprehension, retention, and the development of long-term learning skills. The present study contributes to the literature by elucidating the nuanced mechanisms through which knowledge, experience, and context interact to shape instructional decision-making, offering practical and theoretical insights for both teacher development and policy design. It emphasizes that fostering adaptive, evidence-informed practice is an ongoing process requiring not only individual skill development but also structural and institutional support, highlighting the critical importance of aligning educational policy, teacher training, and classroom realities to optimize the implementation of learning science principles.

CONCLUSION

The findings of this study collectively underscore the intricate relationship between teachers' theoretical knowledge of learning science principles, their practical implementation in instructional settings, and the multifaceted factors that shape reflective adaptation, revealing both the potential and the limitations of translating cognitive science into classroom practice. Teachers demonstrated substantial familiarity with key principles such as retrieval practice and multimodal instruction, reflecting exposure to professional development and research-informed pedagogical strategies, yet the systematic application of these strategies, particularly spaced repetition and structured reflective adaptation, remained inconsistent due to constraints imposed by curriculum demands, limited instructional time, and varying access to resources. The analysis further highlighted that reflective adaptation is not solely a function of knowledge but is significantly mediated by professional experience, teacher confidence, and resource availability, with experienced and confident teachers showing a greater capacity to adjust lessons responsively and implement multiple principles in integrated ways. These dynamics illustrate that effective translation of learning science principles into practice

requires an alignment between individual teacher capacities and institutional structures, including supportive policies, flexible curricula, and professional development opportunities that emphasize both conceptual understanding and practical enactment. Moreover, the study emphasizes the importance of fostering adaptive expertise, whereby teachers are encouraged to engage in deliberate reflection, observe student responses, and make informed instructional adjustments in real time, highlighting the role of experiential learning in enhancing pedagogical effectiveness. The implications extend beyond individual classrooms, suggesting that educational institutions must provide both the material resources and the cognitive scaffolding necessary to enable teachers to operationalize research-based strategies systematically, while professional networks and mentorship can facilitate the sharing of best practices and collaborative problem-solving. In sum, the study affirms that bridging the gap between cognitive science and teaching practice is a complex, context-dependent process that demands attention to teacher knowledge, reflective capacity, institutional constraints, and the provision of practical supports, ultimately contributing to more effective, adaptive, and evidence-informed instruction that can enhance student engagement, comprehension, and long-term learning outcomes in primary education contexts.

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