

 Review Article

Rethinking Science Teaching Through Station Rotation, Flipped Classrooms, and Enhanced Spaced Learning: A Constructivist Perspective

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Abstract

Science education continues to face persistent challenges associated with teacher-centred instruction, including limited student engagement, weak scientific process skills, superficial conceptual understanding, and poor long-term retention. Although numerous student-centred approaches have been proposed, existing research has largely examined instructional strategies in isolation, offering limited guidance on integrating complementary approaches into a coherent framework for science teaching. This paper addresses this gap through a conceptual synthesis of recent empirical and theoretical literature, examining station rotation, flipped classrooms, and enhanced spaced learning through the lens of constructivist learning theory. Drawing on the complementary contributions of Vygotsky, Bruner, and Piaget, the paper examines how each strategy can support a distinct dimension of learning: station rotation promotes collaborative engagement and scaffolded learning, flipped classrooms create opportunities for inquiry and knowledge construction, and enhanced spaced learning supports retention and conceptual consolidation. The paper proposes an integrated constructivist framework in which the three approaches function as a cyclical and mutually reinforcing instructional system. The framework incorporates formative feedback and adaptive responses, allowing any of the three strategies to serve as an entry point according to instructional context and learner needs. Retrieval and revisiting of concepts provide opportunities for consolidation and refinement of understanding, while evidence generated through learning activities can inform subsequent instructional decisions. The proposed framework provides a theoretically grounded model for integrating cognitive, social, and metacognitive dimensions of science learning. Implications are discussed for science teaching, curriculum design, teacher education, and future empirical research examining the effectiveness and underlying mechanisms of integrated instructional systems in diverse educational contexts.

Keywords: Constructivism, Enhanced Spaced Learning, Flipped Classroom, Teaching Methods, Station Rotation

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1. INTRODUCTION

Science education occupies a foundational position in national development, yet students' performance in science subjects across secondary and tertiary institutions still presents significant challenges. Research has consistently documented a decline in students' interest in science, poor academic achievement, and an inability to apply scientific knowledge to real-world problems (Gizaw & Sota, 2023; Laid & Adlaon, 2025). These outcomes are not incidental; they reflect persistent structural weaknesses in how science is taught. In many classrooms in developing countries, teaching remains heavily dependent on approaches, such as lectures, textbook recitation, and rote memorisation, that privilege content delivery over genuine understanding (Mamombe & Mathabathe, 2024; Zvoch et al., 2019). The consequences of

these teaching practices are noticeable as students leave science classrooms unable to acquire skills such as formulating hypotheses, designing experiments, analysing data, or drawing evidence-based conclusions, which are indispensable to scientific literacy and technological advancement (Gizaw & Sota, 2023; Li et al., 2024). This link between instruction and outcomes is reinforced by Abdullah et al. (2024), who demonstrated that instructional strategy is the single strongest predictor of student engagement in science subjects, establishing that poor instructional choices may affect how science students learn. When science classrooms consistently produce disengaged learners who depend on rote procedures rather than inquiry, the nation's long-term capacity for scientific innovation and technological advancement is weakened (Brakhage et al., 2023; Laid & Adlaon, 2025).

Continuous efforts have been made to address these challenges. Several studies have explored a range of pedagogical alternatives, including inquiry-based learning, problem-based learning, hands-on experimentation, gamification, and various technology-integrated approaches (Arifin et al., 2025; Uluçınar, 2023; Zourmpakis et al., 2024). These instructional strategies have produced encouraging results within their respective scopes. For instance, inquiry-based learning has shown a large effect on students' critical thinking skills in science (Arifin et al., 2025), and problem-based learning has been proven to improve academic achievement at secondary and tertiary levels (Uluçınar, 2023). However, the body of existing work still suffers from notable limitations that restrict its practical utility. This is because many studies address single isolated strategies without examining how instructional strategies can be systematically integrated into the science classroom as a coherent pedagogical framework (Laid & Adlaon, 2025; Strat et al., 2024). Furthermore, several promising strategies, particularly those that combine student-centred rotation, pre-class preparation, and deliberate spacing of learning, remain insufficiently theorised in the science education literature, especially at the secondary school level and within under-resourced settings (Jorajuria & Usart, 2025). The practical challenge teachers face is not just knowing that active learning works; it is knowing which specific, classroom-ready strategies can be adopted with clear pedagogical rationale, manageable implementation demands, and broad applicability across diverse science topics. This actionable guidance is precisely what the literature has yet to consolidate.

This paper addresses that gap by examining three instructional strategies, namely station rotation, flipped classrooms, and enhanced spaced learning (ESL), as a coherent, student-centred response to the deficiencies of conventional science teaching. Drawing on constructivist learning theory, which positions learning as an active, socially mediated process rather than passive reception, each strategy is analysed for its theoretical grounding, empirical support, and practical application within the science classroom (Chand, 2023; Vygotsky & Cole, 1978). The station rotation model is examined for its capacity to diversify learning experiences and promote collaborative problem-solving (Cauring et al., 2021; Ramadan et al., 2025), the flipped classroom is explored as a vehicle for redistributing cognitive demand, freeing in-class time for inquiry, peer discussion, and deeper conceptual engagement (Turan, 2023; Wright & Park, 2022), and enhanced spaced learning is considered for its demonstrated ability to improve long-term retention and support higher-order cognitive achievement in science (Muhammed & Mercian, 2024; Yuan, 2022). This paper is conceptual in nature and does not present primary empirical data; rather, it synthesises existing evidence to build a theoretical case for the adoption of these strategies in science classrooms. In doing so, it offers science educators, curriculum designers, and teacher educators a well-grounded and theoretically oriented framework for rethinking how science is taught.

2. LITERATURE REVIEW

2.1. Theoretical Framework

The three instructional strategies examined in this paper are anchored in constructivist learning theory, which posits that learners are not passive recipients of knowledge but actively construct understanding through experience, social interaction, and reflection (Cakir, 2008; Chand, 2023). This theoretical position draws from the work of Piaget, Vygotsky, and Bruner, each of whom contributed a distinct but complementary account of how knowledge develops. Piaget's theory of cognitive development established that learners progress through qualitatively distinct stages of understanding and that genuine learning occurs through the processes of assimilation and accommodation, where new information is either integrated into existing mental schemas or prompts the reorganisation of those schemas (Blake & Pope, 2008). The implication of this for science instruction is that if students are not given opportunities to engage

with new phenomena, make predictions, observe outcomes, and reconcile discrepancies, the kind of cognitive restructuring that produces scientific understanding will not occur.

Vygotsky's sociocultural theory extends this account by emphasising that the nature of cognitive development is fundamentally social. His concept of the Zone of Proximal Development (ZPD) describes the productive space between what a learner can do independently and what they can achieve with guidance from a more capable peer or teacher (Vygotsky & Cole, 1978). This theoretical construct directly justifies instructional strategies that involve collaboration, scaffolded peer interaction, and differentiated support within a shared learning environment. Station rotation, in particular, operationalises the ZPD by creating structured opportunities for peer collaboration, teacher-guided small-group instruction, and independent practice within the same lesson (Mamman et al., 2022). Bruner's discovery learning further complements these positions by arguing that students learn most sturdily when they arrive at understanding through structured inquiry rather than direct transmission (Chand, 2023). The flipped classroom model aligns with this principle by repositioning the teacher's role from transmitter of information to facilitator of discovery, ensuring that valuable face-to-face time is spent on exploration and application rather than exposition.

Constructivism makes a convincing case against the persistence of teacher-centred, lecture-dominated science instruction. As argued by Lombardi and Shipley (2021), active learning, which is the pedagogical offspring of constructivism, consistently outperforms passive instruction when cognitive engagement is both genuine and well-structured. The three strategies this paper examines, namely station rotation, flipped classrooms, and enhanced spaced learning, each translate constructivist principles into practical classroom design. They shift the locus of activity from the teacher to student-centred instruction, from transmission to construction, and from short-term performance to long-term understanding.

2.2. The Problem of Teacher-Centred Instruction in Science Classrooms

The dominance of teacher-centred instruction in science classrooms is well-documented, and its consequences for student learning are consistently negative. Teacher-centred instructional strategies, which rely on direct lecture, lesson or content coverage, and minimal student participation, have been shown to produce surface-level learning that does not transfer to students acquiring scientific skills but to memorisation of concepts (Zvoch et al., 2019). For instance, Mamombe and Mathabathe (2024) compared students taught stoichiometry through active and passive approaches and found that the passive group demonstrated significantly weaker problem-solving competencies, despite being exposed to the same content. Content coverage alone does not produce scientific competence; the manner in which content is encountered matters enormously. When students are treated as passive receivers of information instead of active builders of understanding, they gain procedural familiarity but lack conceptual depth, which makes them unprepared for the demands of scientific inquiry (Gizaw & Sota, 2023; Hardy et al., 2022).

Despite these consequences, teacher-centred instruction persists because of systemic pressures in curriculum, training, and assessment that prioritise coverage and recall over inquiry. First, many science curricula are organised as linear, topic-by-topic sequences that promote the speed of coverage over depth of engagement, effectively penalising teachers who spend time on collaborative or investigative tasks (Strat et al., 2024). Second, pre-service teacher education programmes in many national systems continue to model the very lecture-based instruction that research criticises, leaving graduates without direct experience of student-centred alternatives (Strat et al., 2024). Third, high-stakes examination systems that test factual recall rather than scientific reasoning create rational incentives for teachers to prioritise transmission over inquiry, even where they possess the professional knowledge to do otherwise. The net effect is a generation of science learners who can reproduce facts under examination conditions but cannot design an experiment, evaluate data, or draw a reasoned scientific conclusion, precisely the competencies that scientific literacy and technological participation require (Li et al., 2024). Any instructional framework that genuinely aims to displace teacher-centred practice must account for these structural pressures, not just propose alternatives to them.

2.3. Station Rotation: Diversifying Learning and Cultivating Scientific Skills

The station rotation model is a blended learning approach in which students move through a sequence of learning stations, each designed to engage a distinct mode of learning, within a single class period. Stations typically include a teacher-led small-group instruction station, a collaborative or hands-on activity station, and an independent digital or written task station. This structural variety ensures that students engage with content through multiple modalities within a single lesson, which is particularly valuable in science, where conceptual understanding, procedural skill, and inquiry ability must be developed in tandem.

The station rotation model yields robust learning gains in science by structuring qualitatively distinct, inquiry-rich experiences across disciplines. Meta-analytic and systematic review evidence shows moderate-to-large effects in secondary STEM, with inquiry- and collaboration-based stations producing the strongest achievement outcomes (Jorajuria & Usart, 2025; Ramadan et al., 2025). Subject-specific studies confirm this pattern: chemistry students taught through the station rotation model (SRM) blended learning report higher motivation and achievement than peers in conventional settings, while ICT-integrated stations in physics enhance problem-solving by diversifying cognitive demands across rotations (Ayob et al., 2020; Cauring et al., 2021). The model's rotational structure thus mirrors the multifaceted nature of scientific work rather than simply redistributing content.

Beyond achievement, the station rotation model builds core dimensions of scientific competence and widens access across diverse learning conditions. The rotational format promotes learner autonomy, with pre-service teachers crediting it with gains in critical thinking and collaboration, and junior high students showing higher engagement and more positive attitudes toward science compared to traditional classrooms (Hasnah et al., 2026; Mamman et al., 2022). Such affective gains matter because sustained interest predicts long-term STEM participation (Brakhage et al., 2023). The model also adapts to material constraints: teachers in rural, low-technology schools have successfully redesigned stations using low-resource materials, demonstrating feasibility outside well-resourced school settings (Yılmaz & Fırat, 2026).

2.4. Flipped Classrooms: Reclaiming Classroom Time for Scientific Inquiry

The flipped classroom inverts the conventional relationship between home and school-based learning. Content that would traditionally be delivered through in-class lectures is instead consumed by students at home through pre-recorded video or reading materials, while the time reclaimed in the classroom is dedicated to problem-solving, experimentation, discussion, and peer collaboration. This redistribution of cognitive activity is theoretically significant because it relocates the most demanding, inquiry-oriented tasks to the supervised classroom environment, where teacher support and peer interaction are available, rather than to the home environment, where students face these challenges alone.

Empirical evidence indicates that the flipped classroom strategy is effective in science classrooms, but its effectiveness depends on instructional design rather than structure alone. Meta-analytic and systematic review evidence confirms statistically significant positive effects on science learning outcomes from K-16, with the largest gains in secondary and higher education when lessons feature quality pre-class preparation and collaborative in-class work (Turan, 2023; Wright & Park, 2022), while mixed-method synthesis further shows that content area and implementation quality moderate outcomes and carefully designed flipped lessons produce substantially greater gains than hastily implemented ones (Doğan et al., 2023). These findings indicate that gains arise when the model is leveraged to restructure classroom activity around inquiry, collaboration, and higher-order tasks.

That restructuring of classroom activity produces measurable cognitive and affective improvements. Shifting class time toward problem-solving, collaboration, and contextualised tasks consistently improves critical thinking and conceptual understanding, with gains amplified by structured peer discussion and project-based assessment (Irwanto et al., 2024; Putri et al., 2021; Rapi et al., 2022). Grounding class activities in socio-scientific issues also strengthens students' scientific attitudes (Sugrah et al., 2023). Thus, the strategy functions as a flexible pedagogical framework that remains effective when adapted to local conditions through offline materials and culturally relevant practices, repositioning the teacher as a facilitator of inquiry and enabling conditions for scientific thinking to develop (Ferdiansyah et al., 2025).

2.5. Enhanced Spaced Learning: Strengthening Retention and Higher-Order Achievement

Enhanced spaced learning refers to the deliberate restructuring of lesson sequences so that previously taught content is revisited at strategically distributed intervals, combined with active retrieval tasks and brief, structured consolidation periods between exposures. ESL presents lesson content in short, focused segments, interspersed with brief breaks that include interactive activities such as games, puzzles, peer discussions, and retrieval tasks (Adebisi et al., 2025). These activities create opportunities for teachers to receive feedback and consolidation while requiring students to bring previous ideas back into active use. From a constructivist perspective, retrieval is therefore not limited to testing whether information has been retained. When students are required to explain a concept, interpret a representation, predict an outcome, or justify an answer without immediate access to the original learning material, they reconstruct prior knowledge and connect it with the present task. Their responses can reveal incomplete or inconsistent conceptions, which can then be clarified through feedback, peer discussion, or subsequent learning experiences. Enhanced spaced learning thus combines distributed intervals, active retrieval, and consolidation in ways that support durable retention, continued reconstruction and refinement of understanding (Yuan, 2022; Zhou et al., 2025). Unlike conventional lesson sequences that treat each topic as a discrete, self-contained unit, enhanced spaced learning helps reintroduce prior content within new learning topics, exploiting what cognitive scientists call the spacing effect, which is a well-established finding that memory is stronger and more durable when learning is distributed across time rather than massed in a single session (Yuan, 2022).

Evidence from cognitive psychology and science classrooms consistently positions spaced learning as a powerful strategy for developing both retention and higher-order scientific thinking. At its core, the spacing effect produces substantial long-term retention gains over massed practice, yet students often misjudge massed practice as more effective due to short-term performance illusions, a metacognitive gap that leads to last-minute revision practices that undermine durable conceptual understanding needed for advanced study (Yuan, 2022). When applied to secondary science instruction, restructuring lessons to embed spaced intervals with deliberate rest periods improves retention and conceptual understanding in physics without extending curriculum time, while in chemistry, it drives achievement across all of Bloom's cognitive domains, with the largest gains in analysis, synthesis, and evaluation (Muhammed & Mercian, 2024; Zhou et al., 2025).

Beyond cognitive outcomes, emerging classroom-based evidence highlights its affective benefits. For instance, Adebisi et al. (2025) found that enhanced spaced learning significantly improved secondary school students' attitudes toward Physics, with students exposed to the strategy demonstrating more positive dispositions than those taught using conventional methods, irrespective of gender. These findings are particularly important for science education as they establish that spaced learning is not merely a memory aid for factual recall but a mechanism for developing the higher-order cognitive competencies that scientific thinking demands.

2.6. Synthesis of Evidence on Station Rotation, Flipped Classroom and Enhanced Spaced Learning

The three strategies reviewed in this paper, namely station rotation, flipped classrooms, and enhanced spaced learning, are evidence-based responses to the specific failures of teacher-centred science instruction. Each addresses a distinct dimension of the problem. Station rotation addresses the passivity and uniformity of conventional science lessons by introducing structural variety and collaborative engagement during each class period. The flipped classroom responds to the misallocation of classroom time by redirecting in-class activity towards inquiry, problem-solving, and peer discussion. Enhanced spaced learning responds to the fragility of short-term, massed learning by building retrieval and repetition into the curriculum architecture. These strategies, when deliberately integrated, can constitute a complementary framework rather than competing alternatives, and their integration within science classrooms can offer the prospect of addressing cognitive, affective, and metacognitive dimensions of student learning simultaneously.

What is particularly notable about these three strategies is their shared theoretical lineage and, more practically, the way they will interact when used within the same instructional sequence. For instance, station rotation addresses the within-lesson dimension: a single 40-60 minute period generates conceptual,

procedural, and collaborative engagement through its rotational structure, and the unresolved questions that emerge from hands-on station work supply genuine scientific purpose to the pre-class inquiry tasks that the flipped classroom requires. The flipped classroom can then address the lesson-to-lesson dimension: conclusions that students actively construct during in-class inquiry become the content of the next spaced retrieval interval, ensuring that what has been understood is subsequently consolidated rather than discarded. Enhanced spaced learning can address the unit-level dimension: misconceptions surfaced during retrieval tasks inform the design of the teacher-led station in the following rotation lesson, closing the instructional loop.

In addition, the formative feedback loop could be considered central to this integration because evidence generated at one stage determines the instructional response at the next. For instance, students' pre-class preparation could provide an initial indication of readiness, station activities could reveal how concepts developed are applied and discussed, and spaced retrieval could identify knowledge that has been consolidated as well as misconceptions that remain unresolved. This evidence should inform subsequent decisions about grouping, scaffolding, questioning, task difficulty, and the level of teacher support provided (Hardy et al., 2022). The following instructional cycle can therefore be adjusted to respond to students' demonstrated needs rather than simply repeating a predetermined sequence. The integration is consequently adaptive and cyclical, in that preparation supports active construction, retrieval provides formative diagnosis, and the diagnosis informs the design of subsequent learning experiences (Yuan, 2022; Zhou et al., 2025).

To show how these strategies can work together, consider a biology lesson on cell transport. Before the first face-to-face lesson, students could engage with a short video or reading on diffusion, osmosis, and active transport and complete brief preparatory questions. Their responses provide an initial indication of prior understanding and identify concepts that require greater attention during classroom instruction. In the subsequent lesson, a station rotation strategy could be used to provide four stations of differentiated learning experiences: one station could offer teacher-guided clarification for students who need additional support in distinguishing active from passive transport; another could engage students in a hands-on osmosis investigation; a third could involve collaborative interpretation of diagrams and experimental observations; and a fourth could provide an independent application task. Between stations, brief enhanced spaced learning intervals could be incorporated through activities such as short retrieval quizzes, polls, games, concept questions, or peer discussion, allowing students to revisit and actively retrieve ideas encountered in the preceding station before moving to the next learning experience. During these intervals, students would not simply recall isolated facts but could also be asked to explain, interpret, predict, or justify their responses, thereby providing opportunities to consolidate and refine their developing understanding. Their responses could also provide formative evidence of what has been understood and what remains unclear. Where students continue to confuse active and passive transport, for example, the teacher could revisit the concept through targeted explanation, regrouping, visual representations, or a more appropriately scaffolded task in the next cycle, while students demonstrating secure understanding could be given more challenging applications. A subsequent flipped activity could then extend the revised understanding into a new context before another cycle of rotation and spaced retrieval. In this way, the three strategies are not used in isolation or simply in parallel; the flipped classroom prepares students for classroom engagement, station rotation provides differentiated opportunities for active construction, and the short intervals between stations provide embedded enhanced spaced learning through retrieval and consolidation. Evidence generated through these activities can then inform the design of subsequent learning experiences, creating a cyclical and adaptive process of construction, retrieval, diagnosis, and re-engagement. This is not simply three strategies running in parallel; it is a self-correcting instructional loop in which each strategy creates the conditions the next requires. However, the theoretical framework does not guarantee the quality of implementation. As Robertson (2022) rightly cautions, the flipped classroom is not inherently constructivist but becomes so through intentional design. This caution applies equally to station rotation and spaced learning, but it does justify pursuing integration and provides the criteria by which its quality should be evaluated.

Science teachers seeking to adopt these strategies will nonetheless face real implementation challenges. The station rotation model demands careful planning of differentiated station tasks, the flipped classroom requires reliable student access to pre-class materials and a cultural shift in how students perceive their responsibilities outside the classroom, and enhanced spaced learning requires deliberate curriculum

sequencing that many current syllabi do not support. Hardy et al. (2022) emphasise that adaptive teaching, in which instruction is continuously adjusted in response to student understanding, is critical to effective learning. Therefore, within the proposed framework, adaptation is not an additional strategy operating alongside station rotation, the flipped classroom, and enhanced spaced learning; it is the mechanism through which the three strategies become responsive to differences among learners. For example, evidence from pre-class preparation, station activities, teacher observation, peer interaction, and spaced retrieval can be used to adjust grouping, scaffolding, questioning, task difficulty, and teacher support. Students who demonstrate partial understanding can therefore receive targeted explanation or guided practice, while students who demonstrate secure understanding can be challenged with more complex applications. Such differentiation allows the same instructional cycle to accommodate variation in prior knowledge, pace of learning, confidence, and levels of conceptual understanding without abandoning a common learning goal. Moreover, teacher education is a weak link in inquiry-based reform in teacher preparation programmes that do not give pre-service teachers experiential exposure to these strategies; as a result, classroom implementation tends to remain superficial (Strat et al., 2024). These implementation realities must be honestly acknowledged in any advocacy for instructional reform.

3. THE PROPOSED FRAMEWORK

3.1. Integrated Constructivist Framework for Science Instruction: Theoretical Grounding, Pedagogical Functions, and Classroom Application

The central argument of this paper is not that station rotation, flipped classrooms, and enhanced spaced learning are individually effective, but that their deliberate integration within a shared constructivist framework can simultaneously address the cognitive, social, and temporal dimensions of science learning by combining qualitatively different instructional approaches. This is supported by the fact that constructivism holds that learning is not the passive reception of transmitted information but the active construction of understanding through experience, social interaction, and repeated cognitive engagement with prior knowledge (Cakir, 2008; Chand, 2023). Each of the three strategies operationalises one dimension of this theoretical position: station rotation enacts Vygotsky's Zone of Proximal Development by structuring guided, collaborative, and independent tasks within a single lesson to scaffold learning across the full range of student capability within any given class, the flipped classroom operationalises Bruner's discovery learning by relocating content delivery to the home environment and reclaiming supervised classroom time exclusively for the kind of guided inquiry, peer discussion, and experimental investigation through which students construct rather than receive scientific understanding (Putri et al., 2021; Robertson, 2022), and enhanced spaced learning operationalises Piaget's account of assimilation and accommodation by ensuring that prior knowledge is revisited at deliberate intervals and in new relational settings, creating the productive cognitive conflict that forces schema reorganisation rather than mere re-reading (Blake & Pope, 2008; Muhammed & Mercian, 2024).

Critically, the three strategies do not just run in parallel or follow a fixed sequence; they are intended to interact cyclically, with each providing opportunities that can support the use of the others. Station-based activities can generate questions, observations, and developing understandings that can inform subsequent inquiry or preparation; material encountered through flipped learning can provide a basis for later retrieval and consolidation; and retrieval can provide formative evidence that informs subsequent instructional decisions. Therefore, the proposed relationships describe the framework's pedagogical logic rather than a prescribed sequence, with the appropriate entry point and combination of strategies adaptable to instructional context and learner needs (Hardy et al., 2022; Li et al., 2024). Figure 1 presents the full framework, mapping the theoretical grounding, distinct pedagogical functions, interactions, and the classroom conditions each strategy requires for effective implementation.

Figure 1 makes visible what the individual literatures on each strategy leave implicit: that station rotation, flipped classrooms, and enhanced spaced learning are not competing pedagogical options but theoretically complementary strategies that address different temporal and cognitive dimensions of the same learning problem. Station rotation addresses the within-lesson dimension, ensuring that a single 40-60-minute period generates conceptual, procedural, and collaborative engagement with science content rather than one-dimensional exposure (Jorajuria & Usart, 2025; Ramadan et al., 2025). The flipped classroom addresses the lesson-to-lesson dimension, ensuring that the most cognitively demanding, inquiry-

oriented tasks are assigned to the supervised environment where peer interaction and teacher facilitation are available rather than left to students to navigate alone at home (Turan, 2023; Wright & Park, 2022). Enhanced spaced learning addresses the unit-to-unit and curriculum-level dimension, ensuring that the understanding developed within individual lessons is revisited, retrieved, and extended at intervals that cognitive science has consistently shown to produce durable, transferable learning (Yuan, 2022; Zhou et al., 2025).

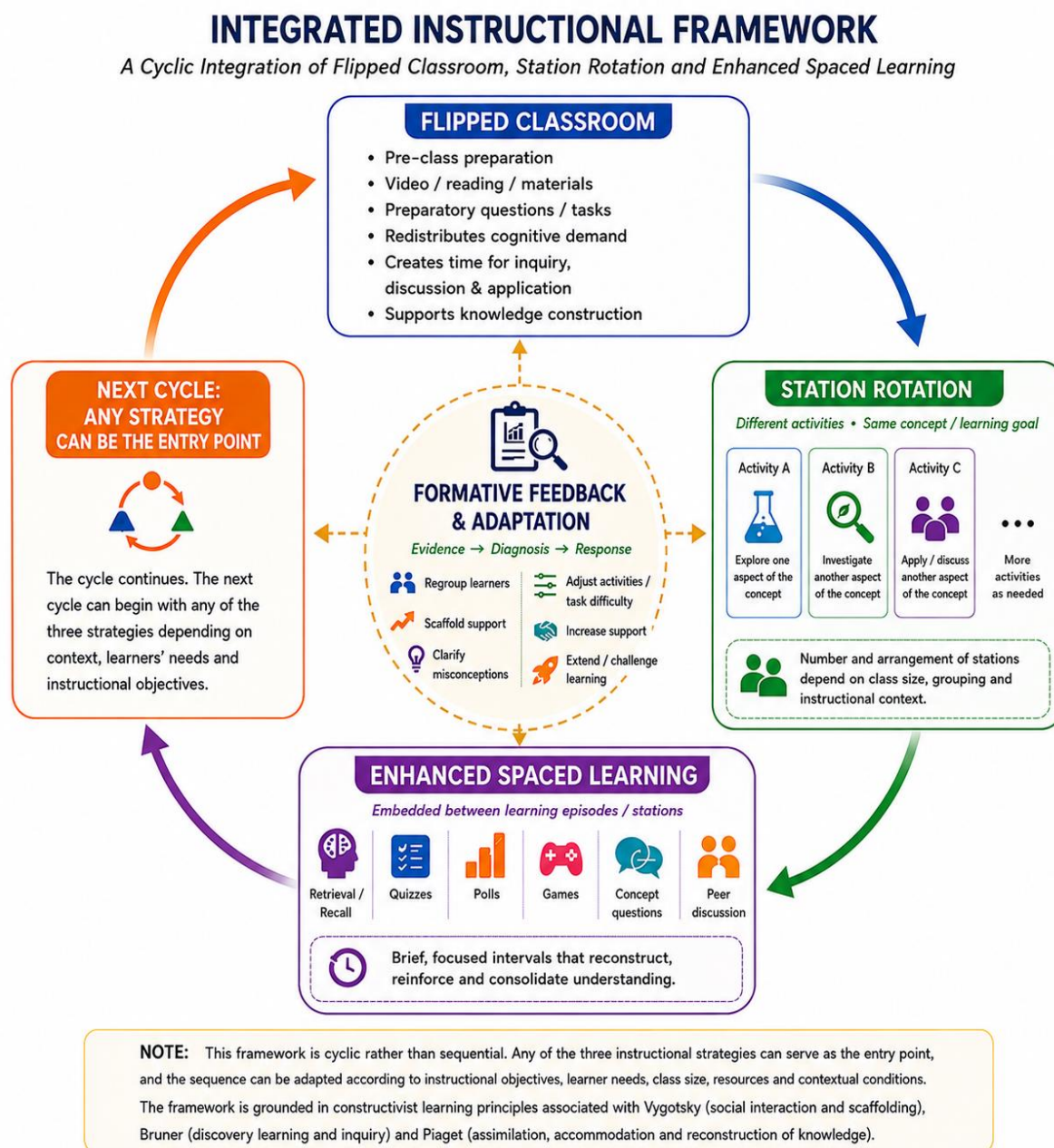


Figure 1. Integrated Constructivist Framework for Science Instruction Combining Rotation, Flipped Classroom and Enhanced Spaced Learning Instructional Strategies

The classroom application section of the framework is equally important: it is worth acknowledging that implementation quality is a critical moderator of each strategy's effectiveness (Doğan et al., 2023; Hardy et al., 2022), and it situates each strategy's requirements within the practical realities of diverse school settings, including resource-constrained classrooms where low-technology station adaptations and culturally contextualised flipped materials have demonstrated genuine effectiveness (Ferdiansyah et al., 2025; Yılmaz & Fırat, 2026). Science educators, curriculum developers, and teacher educators should read this framework not as a rigid prescription but as a theoretically grounded and empirically supported map

of how three evidence-based strategies can be combined to create the kind of active, collaborative, and cognitively demanding science learning environment that constructivist theory has long argued for and that students' measurable outcomes so consistently require.

3.2. Implications for Practice

The evidence reviewed in this paper carries clear and actionable implications for science educators, school administrators, teacher educators, and curriculum developers. Science teachers are encouraged to begin with the station rotation model as an entry point into student-centred instruction, given its structural flexibility and capacity to accommodate mixed-ability classrooms without requiring a complete overhaul of existing resources. Within the integrated framework, however, formative evidence generated throughout the cycle should guide differentiation. Teachers can use pre-class responses, station performance, classroom observation, and retrieval responses to determine when students require additional scaffolding, regrouping, alternative representations, or more challenging applications.

Teacher educators are urged to incorporate direct, experiential engagement with all three models into pre-service science teacher training, moving beyond theoretical introduction to structured practice with reflective debriefing. Curriculum developers should examine the extent to which current science syllabi create space for spaced retrieval practice, as the evidence from Yuan (2022), Zhou et al. (2025), and Muhammed and Mercian (2024) strongly suggests that the linear, topic-by-topic structure of most science curricula actively weakens long-term retention and higher-order thinking and understanding.

4. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

Science classrooms in many parts of the world remain teacher-centred, and the consequences for student scientific literacy, process skill development, and sustained interest in science are well-evidenced and serious. Drawing on the synthesis of recent empirical and theoretical literature, this paper argues that station rotation, flipped classrooms, and enhanced spaced learning represent a theoretically grounded and practically viable response to this problem. Station rotation diversifies the learning experience within each lesson and creates structured opportunities for collaboration and inquiry. The flipped classroom reclaims classroom time for the kinds of active, investigative tasks that genuine scientific thinking requires. Enhanced spaced learning supports durable understanding by combining distributed revisiting and retrieval with opportunities for learners to reconstruct, consolidate, and refine previously developed knowledge. When understood and implemented within a constructivist framework and supported by sustained teacher professional development, these three strategies can transform the quality of science education.

Future research should move beyond evaluating these strategies primarily through learning outcomes and examine the mechanisms through which their cyclical integration produces change. Future studies should consider conducting intervention studies to assess the effectiveness of station rotation, the flipped classroom, and enhanced spaced learning when integrated within a single instructional cycle. Such studies should examine not only academic achievement, scientific process skills, conceptual understanding, and long-term retention, but also the mediating variables that may explain how and why the framework influences student learning. Variables such as self-directed learning, metacognitive awareness, academic resilience, collaborative competence, learner autonomy, and cognitive engagement may provide valuable insight into the processes through which the integrated framework produces learning gains. Examining these mechanisms alongside learning outcomes would clarify not only whether the framework is effective, but also why it works, for whom it works, and under what instructional conditions its effects are strongest.

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Research Ethics. Ethical approval was not required for this study because the manuscript is a conceptual paper based on the synthesis of existing literature and did not involve human participants, animals, or primary data collection. However, the study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki.

Data Availability Statement. No primary datasets were generated or analysed during the current study. All information discussed in this manuscript is derived from published literature cited in the reference list.

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AI Statement. OpenAI's ChatGPT was used to generate the visual representation of the proposed framework presented in Figure 1. The authors reviewed and verified the AI-generated visual output and take full responsibility for the content and accuracy of the published work.

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