

ROLE OF METACOGNITIVE LEARNING STRATEGY IN IMPROVING METACOGNITION SKILLS IN SCIENCE, TECHNOLOGY ENGINEERING AND MATHEMATICS (STEM)

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Abstract: The integration of metacognitive learning strategies in STEM education plays a pivotal role in developing self-regulated, adaptable, and innovative learners. These strategies empower students to plan, monitor, and reflect on their learning processes, fostering critical skills such as problem-solving, adaptability, and resilience. By emphasizing metacognition, educators equip students with the tools necessary for lifelong learning, ensuring their preparedness for academic and professional success in STEM fields. While challenges in implementation persist, the numerous benefits—enhanced learning outcomes, greater independence, and increased confidence—highlight the importance of these strategies in shaping knowledgeable, self-aware individuals capable of thriving in a dynamic, technology-driven world. Therefore, this paper considers the role of metacognitive learning strategy in improving metacognition skills in science, technology engineering and mathematics (STEM) in order to stimulate debate and offer insights.

Keywords: Metacognitive Learning Strategy, Metacognition Skills, STEM

Introduction

Science and technology are essential in the modern world, as they not only drive economic growth but also support vital areas such as healthcare, food production, communication, and environmental conservation. For example, advancements in medical research and technologies have increased life expectancy and improved quality of healthcare. In agriculture, biotechnology and genetics have helped produce resilient crops, enhancing food security globally. The role of Science, Technology, Engineering and Mathematics (STEM) is particularly crucial in nations like Nigeria, where scientific and technological literacy can accelerate development and improve quality of life. Embracing STEM helps bridge developmental gaps, bringing solutions to local challenges through innovative approaches tailored to specific needs, such as renewable energy

for off-grid communities, which directly impacts the country's economic and social progress. Recognizing the importance of chemistry to STEM, the Nigerian National Curriculum for Senior Secondary Chemistry (2012) emphasizes hands-on learning, problem-solving, and critical thinking which are elements of metacognition. Metacognition—the ability to evaluate, regulate, and reflect on one's own learning process—is crucial in STEM education. In complex subjects like chemistry, where abstract concepts often pose learning challenges, metacognitive strategies can help students break down difficult material, plan their learning, monitor their understanding, and adjust approaches as needed. Metacognitive strategies allow students to take ownership of their learning, making them more adaptable, self-regulated, and resilient learners. This approach aligns with modern educational trends

emphasizing critical thinking, problem-solving, and lifelong learning skills, which are necessary in STEM fields. Applying metacognitive learning strategies in STEM education helps students develop higher-order thinking skills necessary for scientific inquiry and problem-solving. Students who actively engage in metacognitive practices—such as assessing their strengths and weaknesses, tracking their progress, and adjusting study methods—are better prepared to tackle STEM-related challenges in real-world contexts. For example, a chemistry student using metacognition may approach a lab experiment by first reflecting on past experiments, setting specific goals for the current lab, and analyzing outcomes to refine future methods. Therefore, the integration of science and technology, as well as the application of metacognitive strategies in education, are foundational to a society's progress. By advancing STEM literacy and incorporating metacognitive learning, countries like Nigeria can equip students with the skills needed for innovation, resilience, and problem-solving in a globalized and rapidly evolving technological landscape.

Metacognitive Learning Strategy

The concept of metacognitive learning strategies emerged in the 1970s and 1980s with the pioneering work of researchers like John Flavell and Ann Brown. Flavell (1976) introduced "metacognition" as a way to describe how individuals reflect on their own thought processes, laying the groundwork for further research. Ann Brown (1980) expanded on this concept with "metacognitive awareness," which involves being consciously aware of one's learning strategies, and introduced techniques to promote metacognition in students. Their research showed that when students think critically about their learning, they can better control it, leading to more effective and enduring educational outcomes. These foundational ideas have evolved into core strategies used across educational settings, especially in STEM,

where complex and layered knowledge demands self-regulated learning. Metacognitive learning strategies are crucial in the context of Science, Technology, Engineering, and Mathematics (STEM) as they foster self-awareness in students, enabling them to take an active role in their learning. In fields that require complex problem-solving and critical thinking—such as chemistry, physics, and engineering—students benefit from strategies that help them reflect on their understanding, recognize gaps in knowledge, and adapt their approach to challenging concepts. These strategies are aligned with the objectives of the Nigerian National Curriculum for Senior Secondary Chemistry (2012), which emphasizes practical, critical thinking, and self-directed learning skills necessary for a science-driven global economy.

Core Components of Metacognitive Learning Strategies

1. Planning and Goal Setting: Metacognitive learning encourages students to set specific learning goals and make strategic plans to approach challenging STEM topics. For instance, a chemistry student might set a goal to master organic reaction mechanisms by breaking down the topic into manageable parts, planning study sessions for each part, and then reflecting on their understanding after each session. As Cornell University (2024) emphasizes, these strategies enable students to be proactive in their learning, laying a strong foundation for academic and professional success.

2. Monitoring Understanding and Learning Strategies: In STEM fields, where concepts can be highly abstract and layered, students often struggle to gauge their understanding without consistent self-monitoring. Metacognitive learning strategies teach students to regularly check their comprehension as they progress through complex material. For example, a physics student learning about thermodynamics might use self-questioning

techniques to test their understanding after each lecture. By doing this, students identify misunderstandings early, allowing them to seek help or adjust their strategies. This skill is essential in STEM as it builds a habit of critical assessment that leads to more effective learning and problem-solving.

3. Evaluating and Adjusting Learning Strategies:

Metacognitive learning also involves evaluating the effectiveness of one's study strategies and making adjustments as necessary. In STEM education, where methods and strategies may vary greatly between disciplines, students benefit from adapting their approaches. For example, an engineering student might realize that working through practice problems is more effective for understanding mechanical principles than passive reading. By recognizing and choosing more effective learning techniques, students enhance their problem-solving abilities and overall academic performance, preparing them for real-world challenges.

4. Reflecting on Learning Outcomes and Identifying Areas for Improvement:

Reflection is a powerful tool in STEM learning, enabling students to look back on their achievements and setbacks, recognize what worked, and identify areas that need improvement. This reflective practice helps students build resilience and a growth mindset, which is especially beneficial in STEM, where setbacks are common. Reflecting on outcomes also encourages a sense of ownership over one's learning, empowering students to persist through difficult material. For instance, a student in computer science who struggled with coding logic might reflect on past difficulties, identify specific logic gaps, and focus on practicing similar problems until they master the concept.

5. Developing a Growth Mindset and Persistence through Challenges:

Metacognitive strategies reinforce a growth mindset, where students view challenges as opportunities for growth rather than

barriers. In STEM fields, where breakthroughs often require persistence and resilience, this mindset is essential. According to research by Dweck (2006), students with a growth mindset are more likely to embrace challenges, persist through difficulties, and ultimately achieve higher academic performance. For STEM students, the ability to stay motivated and adapt their learning in the face of challenging content is critical for success in advanced fields like engineering and technology. The application of metacognitive learning strategies in STEM today recognizes the value of metacognitive strategies, especially in preparing students for STEM careers. The use of these strategies is now widespread across all education levels, from elementary to university, and beyond. Institutions worldwide are incorporating metacognitive training into STEM curricula to develop students' abilities to self-assess, plan effectively, and adjust strategies based on feedback. For example, many chemistry curricula now integrate metacognitive learning techniques like "think-aloud" protocols, where students verbalize their thought process while solving problems, helping them recognize and correct errors in real-time.

The Impact of Metacognitive Learning Strategies are invaluable in STEM careers where continuous learning, adaptation, and problem-solving are required. A scientist, for example, must be able to reflect on experimental results and evaluate research methodologies, while an engineer must adjust project strategies based on real-time data and feedback. By cultivating metacognitive skills in students, educational institutions prepare graduates for the demands of rapidly evolving STEM fields. Professionals who are adept at self-regulation are often more innovative, resilient, and effective in tackling complex challenges in science, technology, engineering, and mathematics. Hence, metacognitive learning strategies play a pivotal role in developing

self-regulated learners who can adapt, innovate, and succeed in STEM fields. These strategies help students become conscious of their learning processes, enabling them to plan, monitor, and reflect on their academic journeys. By encouraging a growth mindset and teaching adaptive learning techniques, educators equip students with skills that will support them throughout their academic careers and in professional STEM fields. The development and integration of metacognitive learning strategies, initiated by early researchers like Flavell and Brown, remain relevant today as STEM education strives to cultivate not just knowledgeable students but also self-aware, lifelong learners prepared for the challenges of a dynamic world.

Implementation of Metacognitive Learning Strategy

The effective implementation of metacognitive learning strategies in STEM—particularly in subjects like chemistry—requires a systematic approach that encourages students to reflect on their learning, self-assess, and actively engage with complex material. Implementing these strategies can significantly enhance students' understanding, critical thinking, and problem-solving skills, preparing them to tackle STEM challenges independently. In recent studies, researchers have explored various techniques to improve the quality of learning in STEM through metacognitive strategies, with positive outcomes in both university and secondary school contexts. Hence, the Key Techniques for Implementing Metacognitive Learning Strategies are:

1. Reflective Self-Assessment: Encouraging students to assess their understanding of chemical concepts is foundational to metacognitive learning. In practice, this can involve asking students to identify areas they find challenging, articulate what they do and do not understand, and prioritize topics for further study. This approach fosters a habit of self-reflection, enabling students to take ownership

of their learning. For instance, by regularly prompting students to use statements such as "I understand this," "I'm confused about this part," or "I need more practice with this," teachers can cultivate a language of self-awareness in the classroom, which Cornell University (2024) identifies as essential for developing self-regulated learners.

2. Concept Mapping and Diagramming: Concept maps or diagrams are effective tools for helping students visualize and connect complex concepts, which is especially beneficial in chemistry, where understanding relationships between elements, compounds, and reactions is crucial. This strategy allows students to organize their thoughts, make connections between topics, and deepen their understanding. Research suggests that organizing information visually helps students integrate knowledge, retain material, and engage in deeper levels of learning. Concept maps have also been shown to help in subjects like biology and physics, where interconnected ideas are key.

3. Think-Aloud Protocols: Think-aloud protocols involve teachers or students verbalizing their thought process as they solve problems, which models critical thinking and problem-solving strategies for peers. By listening to these verbalized thought processes, students gain insight into effective approaches and strategies. This technique has been particularly effective in chemistry and mathematics education, where following a logical progression in problem-solving is essential. When students practice thinking aloud, they become more aware of their cognitive processes, recognize mistakes, and can adjust their approach to improve outcomes.

4. Self-Assessment and Feedback Loops: Providing students with constructive feedback and encouraging self-assessment is key to metacognitive learning. Through regular feedback, students can gauge their progress, identify misconceptions, and refine their learning strategies. For example, after

completing a lab report, students might evaluate their work using a checklist, reflecting on areas where they succeeded and where they could improve. This practice not only strengthens students' understanding of specific concepts but also builds a habit of continuous improvement—a valuable skill in STEM.

5. Incorporating Technology in Metacognitive Learning: Technology, such as online simulations, virtual labs, and interactive platforms, supports metacognitive learning by providing dynamic, hands-on experiences. In chemistry, for example, virtual labs enable students to experiment with different reactions safely and at their own pace, encouraging them to test their understanding, observe outcomes, and reflect on their approach. Online tools allow students to experiment without the constraints of physical labs, making them useful for visualizing abstract concepts, testing hypotheses, and enhancing engagement.

6. Peer-to-Peer Learning and Discussion: Collaborating in pairs or small groups enables students to articulate their understanding and exchange perspectives, reinforcing metacognitive skills through peer learning. In this setup, students can compare strategies, clarify misunderstandings, and help each other navigate complex concepts. Studies show that group work enhances students' metacognitive awareness, as explaining their reasoning to peers encourages them to reflect on their thought processes, fostering a deeper understanding and a shared learning experience.

7. Goal Setting and Reflection: Setting learning goals and reflecting on progress fosters a growth mindset and helps students to stay motivated in challenging subjects like chemistry. Teachers can guide students to set specific, achievable goals (e.g., mastering stoichiometry by the end of the week) and periodically reflect on their progress. Reflection exercises allow students to recognize their progress and recalibrate their efforts, helping them become

more resilient and self-directed learners. In line with the implementation of Metacognitive Learning Strategy, the following research were carried out:

1. University-Level Research: Research by Ermolayev, Keberle, and Borue (2013) and by Yogica and Helendra (2018) at the university level demonstrates that metacognitive learning strategies improve both extrinsic and intrinsic motivation. Ermolayev et al. (2013) used peer evaluation, where students reviewed each other's work, fostering extrinsic motivation through accountability and quality standards. This method encouraged students to be more objective and thorough in their evaluations, which indirectly improved their own understanding. In contrast, Yogica and Helendra's (2018) approach, "they do it, they get it, and they know it," focused on intrinsic motivation and comprehension. Their findings suggest that when students actively engage in self-directed learning, their understanding and retention improve significantly, which is beneficial in STEM fields requiring in-depth knowledge.

2. Secondary School Research: At the secondary school level, Yang and Dong (2017) and Zou, Li, Chen, Zhong, and Wang (2014) applied Bloom's taxonomy and the SOLO taxonomy to enhance learning quality. Yang and Dong's (2017) research involved using a Diffuse Cognitive Map based on a Student Attribute Model (SAM) to monitor student progress. This method incorporated performance-based and non-performance-based learning attributes, such as the knowledge construction indicator (KCI) and student growth indicator (SGI). Such detailed indicators help teachers assess students' progress comprehensively, allowing for targeted metacognitive interventions that promote self-regulated learning. Zou et al. (2014) utilized the SOLO taxonomy to assess students' learning approaches and categorize them into superficial, deep, and achievement levels. By assessing students'

learning motives and strategies (e.g., surface learning motive vs. deep learning strategy), they identified factors that influence learning quality. Their findings highlight that students who engaged in deep learning and achievement-oriented strategies demonstrated higher levels of comprehension and mastery. Applying these findings in chemistry and other STEM fields can help teachers encourage students to pursue deeper, more meaningful engagement with the material using metacognitive learning strategy. Therefore, irrespective of existence of a knowledge gap in the application of metacognitive strategies to improve learning quality of secondary school students, Chemistry teachers can use these research-based strategies to foster metacognitive skills in students, enabling them to better understand chemical concepts, refine problem-solving methods, and grow as independent learners. For example, implementing peer review of lab reports or using concept mapping exercises in class can provide students with concrete tools to assess their knowledge, adjust their approach, and address any gaps. As chemistry often involves layered and interconnected concepts, these methods help students build a coherent understanding of the subject and develop a metacognitive mindset that supports lifelong learning.

Advantages of Metacognitive Learning Strategy:

Implementing metacognitive learning strategies in Science, Technology, Engineering, and Mathematics (STEM) education offers numerous advantages, helping students develop skills that are essential for both academic and real-world success. By fostering intentional and reflective learning practices, these strategies improve various cognitive, personal, and academic skills, making students more adept in STEM disciplines and better prepared for lifelong learning.

1. Improved Learning Outcomes: Metacognitive learning strategies help students develop a deeper

understanding of complex STEM concepts. By reflecting on their learning methods, students retain information better and improve their application of knowledge. For instance, when students practice self-assessment after solving chemistry or mathematics problems, they identify areas where they need further understanding, ultimately improving retention and long-term learning. Research indicates that students who engage in metacognitive activities often experience greater academic success due to this depth of understanding (Cornell University, 2024).

2. Enhanced Problem-Solving Skills:

Metacognitive strategies encourage critical thinking, an essential skill for problem-solving in STEM fields. As students learn to evaluate their approaches to complex tasks, they become more adaptable and creative in finding solutions. For example, in engineering, students who apply metacognitive strategies are more likely to assess a problem from multiple angles, leading to innovative solutions. Studies have shown that metacognitive learners are better at breaking down problems and considering different methodologies, thus enhancing their analytical and critical thinking skills (Yogica & Helendra, 2018).

3. Increased Self-Awareness: Metacognition promotes self-awareness, enabling students to identify their strengths, weaknesses, and preferred learning styles. Understanding personal learning preferences is particularly beneficial in STEM, where students often encounter varied and challenging material. By being aware of their own cognitive tendencies, students can adapt their learning approaches for different types of content, improving comprehension and retention (Flavell, 1976).

4. Better Time Management: In STEM education, where tasks often require significant time and concentration, metacognitive strategies aid students

in prioritizing tasks and managing time effectively. When students develop skills to evaluate the complexity of tasks and allocate time accordingly, they become more organized and capable of handling multiple assignments. This skill is especially relevant in fast-paced academic settings and is linked to higher academic performance and reduced stress (Yang & Dong, 2017).

5. Improved Self-Regulation: Self-regulation involves managing one's emotions, motivation, and behavior, which are essential skills in STEM learning. Metacognitive strategies teach students to set goals, monitor their progress, and adjust their efforts as needed. This leads to better concentration, resilience, and persistence when facing challenging topics. Studies show that students with high self-regulation skills tend to be more motivated and resilient in STEM courses, which often require sustained effort and perseverance (Ermolayev, Keberle, & Borue, 2013).

6. Enhanced Transfer of Learning: Metacognitive strategies facilitate knowledge transfer, allowing students to apply learned concepts to new situations. This skill is particularly valuable in STEM, where cross-disciplinary knowledge is often required. For example, a student who understands principles of physics may apply them in engineering tasks. This transferability fosters a deeper and more flexible understanding of STEM content and is highly valued in the workforce, where interdisciplinary problem-solving is common (Zou et al., 2014).

7. Increased Independence: Metacognitive learning strategies cultivate self-directed learning, which encourages students to take ownership of their education. In STEM, where independent research and project work are common, self-direction enables students to explore topics in greater depth without constant guidance. This independence not only improves academic performance but also prepares

students to thrive in professional environments that value self-sufficiency and initiative (Brown, 1980).

8. Improved Communication Skills: Engaging in metacognitive practices enhances students' ability to communicate their thoughts and ideas effectively. In STEM education, articulating reasoning and explaining complex processes are critical, particularly in group projects, presentations, and lab reports. Metacognition helps students structure their ideas logically, making it easier for them to share insights with peers and instructors (Cornell University, 2024).

9. Greater Confidence: Through goal-setting, self-assessment, and reflective practice, students build a growth mindset, fostering resilience and confidence. In STEM, where failure is often part of the learning process, confidence helps students persist through setbacks. Students who believe in their ability to improve and adapt are more likely to tackle difficult problems, take on new challenges, and achieve academic success (Yogica & Helendra, 2018).

10. Lifelong Learning: STEM fields are constantly evolving, and the ability to learn continuously is essential. Metacognitive strategies equip students with the skills necessary for lifelong learning, such as adaptability, self-assessment, and a growth mindset. By fostering a reflective approach to learning, these strategies prepare students to continually update their knowledge and skills, which is crucial in a rapidly changing technological world. Lifelong learning skills are beneficial in any career path and ensure that students can remain relevant and competitive in the workforce (Ermolayev et al., 2013).

Disadvantages of Metacognitive Learning Strategy:

While metacognitive learning strategies provide several benefits, they also present challenges that educators and students must navigate carefully, especially in Science, Technology, Engineering, and

Mathematics (STEM) fields. These potential drawbacks can affect student engagement and learning outcomes but can often be mitigated with thoughtful implementation, targeted support, and structured scaffolding.

1. Cognitive Overload: Metacognitive tasks require additional mental effort, which can lead to cognitive overload. In STEM fields, where students already face complex concepts and intensive problem-solving, the added layer of reflection and self-assessment can be overwhelming. For instance, in subjects like physics or calculus, students may struggle to balance the demands of solving intricate problems with the metacognitive task of evaluating their approach and understanding. Studies indicate that excessive mental load can reduce students' ability to focus on and retain new material, thereby limiting the effectiveness of metacognitive practices (Cornell University, 2024).

2. Increased Anxiety: Metacognitive learning strategies can heighten anxiety, especially for students who struggle with self-assessment or who are less confident in their abilities. In STEM, where students often face high expectations and rigorous assessments, the need to continually evaluate their performance can create additional stress. For example, a student who doubts their mathematical skills might feel intimidated by the self-reflection required in metacognitive activities, leading to reduced confidence and possibly avoidance of the subject matter (Yang & Dong, 2017).

3. Overemphasis on Self-Reflection: While self-reflection is valuable, excessive focus on metacognitive practices can detract from active learning. If students spend too much time analyzing their learning process rather than engaging with content, they may lose out on meaningful practice and application. In STEM fields, which often require hands-on activities and problem-solving, this imbalance can hinder students from fully engaging

with experiments or projects (Yogica & Helendra, 2018).

4. Difficulty in Transferring Skills: Metacognitive skills may not transfer easily across different contexts or subjects. For example, a student who has developed metacognitive strategies for learning biology may struggle to apply them to physics, which requires different problem-solving approaches. This can result in inconsistencies in student performance across STEM fields, as each discipline may demand unique thinking and learning techniques. Research shows that students often need additional support and practice to effectively transfer metacognitive skills between subjects (Zou et al., 2014).

5. Teacher Training: Effective implementation of metacognitive strategies requires teachers to be well-trained in these methods, but such training can be resource-intensive and time-consuming. In many STEM programs, teachers may already be stretched with existing curriculum requirements and may lack the time or resources to develop metacognitive teaching skills. Without adequate training, teachers may struggle to facilitate metacognitive practices, limiting their effectiveness for students (Ermolayev, Keberle, & Borue, 2013).

6. Student Resistance: Some students may resist engaging in metacognitive activities, viewing them as unnecessary or uncomfortable. In STEM, where students might prefer concrete problem-solving over introspection, they may perceive metacognitive tasks as irrelevant. Additionally, students who are not accustomed to reflecting on their learning might find it challenging and avoid the process, missing out on the benefits of metacognitive development (Brown, 1980).

7. Assessment Challenges: Evaluating metacognitive skills is difficult, as these skills are internal and not directly observable. In STEM education, where assessment is often based on

quantifiable achievements (like solving equations or conducting experiments), measuring metacognition can be challenging. Teachers may struggle to design assessments that accurately capture students' metacognitive abilities, and without effective evaluation, it is difficult to provide feedback that supports improvement in these areas (Yang & Dong, 2017).

8. Time-Consuming: Metacognitive activities can require a significant amount of class time. In STEM curricula, where there is often a high volume of material to cover, dedicating time to self-reflection and metacognitive tasks may reduce the time available for core content. For example, in a chemistry class, time spent on metacognitive discussions might detract from practical lab activities or coverage of foundational concepts (Yogica & Helendra, 2018).

9. Potential for Overreliance: While metacognitive strategies are valuable, an overemphasis on them may cause students to neglect other important learning approaches, such as collaboration, hands-on experimentation, or rote learning when appropriate. STEM education often requires a blend of strategies, and an exclusive focus on metacognition might lead students to overlook the value of these complementary methods. Ensuring that metacognitive strategies are integrated in balance with other techniques is crucial to avoid an overreliance that could hinder well-rounded learning (Flavell, 1976).

METACOGNITION SKILLS

Metacognition Skills in the context of STEM, especially in chemistry, highlights how each of these skills supports students in developing a structured, mindful, and self-directed approach to learning and problem-solving. These skills collectively enhance students' ability to tackle complex STEM concepts, become effective learners, and approach challenges with resilience and adaptability.

1. Self-awareness Skill

Self-awareness involves students recognizing their strengths, weaknesses, and areas where they lack knowledge. In chemistry, for example, self-aware students are more likely to identify which topics they find challenging, such as stoichiometry or chemical equilibrium, and can then seek additional resources or assistance. Self-awareness helps students become proactive in addressing their learning needs, ultimately leading to improved academic performance and a more tailored approach to studying. Research shows that self-awareness directly contributes to academic success as it allows students to align their learning strategies with their unique needs (Cornell University, 2024).

2. Planning Skill

Effective planning is crucial in STEM fields, where problem-solving often requires a multi-step approach. In chemistry, planning helps students set realistic goals, prioritize tasks, and allocate time to understand complex concepts like reaction mechanisms or organic synthesis. Planning also includes setting timelines for completing assignments or preparing for exams. Developing a clear, structured approach to tackling problems or projects allows students to manage their workload efficiently, which is vital in rigorous subjects like chemistry where cumulative knowledge is essential for progress.

3. Monitoring Skill

Monitoring involves actively tracking one's progress, identifying any obstacles, and making necessary adjustments to strategies. For STEM students, this skill is crucial as they engage in experiments, complex calculations, or multi-phase projects. Chemistry students, for instance, can monitor their understanding of reaction rates or pH calculations and adjust their study methods if they encounter difficulties. Monitoring helps students stay aware of their comprehension in real time, enabling them to

seek help or modify their study tactics before falling behind (Zou et al., 2014).

4. Evaluating Skill

Evaluation entails assessing the effectiveness and quality of one's thinking and learning. For example, chemistry students might evaluate whether their approach to solving chemical equations or understanding molecular structures is effective by reviewing their results on practice problems or exams. Evaluation enables students to critically reflect on their learning strategies and make informed decisions on which methods to continue, modify, or abandon. In STEM fields, where there is often more than one way to approach a problem, strong evaluation skills allow students to identify the most effective strategies for their success.

5. Self-regulation Skill

Self-regulation is the ability to manage emotions, motivation, and behaviors to stay focused and achieve goals. In challenging STEM fields, self-regulation can prevent students from becoming discouraged when facing difficult concepts or demanding tasks. For example, a chemistry student might use self-regulation skills to manage frustration when struggling with complex organic chemistry reactions, staying motivated to persist despite the challenge. Self-regulation helps students maintain steady progress and resilience, which are essential in rigorous disciplines.

6. Problem-solving Skill

Problem-solving in metacognition involves using strategies to tackle cognitive and metacognitive challenges, such as breaking down complex tasks, analyzing underlying principles, and experimenting with different methods. In STEM, especially in chemistry, problem-solving is integral to learning. Students must often navigate unfamiliar problems or experiments, such as calculating chemical yields or analyzing spectroscopic data, where they need a structured approach. Strong problem-solving skills

allow students to engage deeply with the material, enabling them to approach challenges with a methodical and confident mindset (Ermolayev, Keberle, & Borue, 2013).

7. Cognitive Flexibility Skill

Cognitive flexibility refers to the ability to switch between different strategies, perspectives, or representations to adapt to new information or challenges. In STEM, students often encounter problems that require creative solutions and adaptability. For example, chemistry students might need to shift between visualizing molecular structures in 3D and calculating stoichiometric relationships using algebraic equations. Cognitive flexibility allows students to approach problems from multiple angles, making it easier to understand complex concepts and adapt when facing unexpected challenges (Yang & Dong, 2017).

Conclusion

The integration of metacognitive learning strategies in STEM education is essential for fostering self-regulated, adaptable, and innovative learners. These strategies enhance students' ability to plan, monitor, and reflect on their learning processes, enabling them to develop critical skills like problem-solving, adaptability, and resilience. By equipping students with the tools for lifelong learning, educators prepare them for success in both academic and professional STEM fields. Despite challenges in implementation, the benefits of metacognitive strategies—ranging from improved learning outcomes to greater independence and confidence—make them indispensable in cultivating knowledgeable, self-aware individuals ready to thrive in a dynamic, technology-driven world.

Recommendations:

Considering the benefits of metacognitive learning strategy discussed, the following recommendations are advised:

1. Teacher Training and Professional Development:

Provide educators with comprehensive training on metacognitive teaching strategies, emphasizing how to integrate these approaches effectively in STEM education. This includes workshops on fostering self-reflection, goal-setting, and adaptive learning techniques.

2. Curriculum Design: Incorporate metacognitive strategies into STEM curricula by embedding activities that require students to plan, monitor, and evaluate their learning. For example, assignments could include reflective journals, self-assessment tools, or problem-solving tasks that promote critical thinking and independence.

3. Student Support Programs: Establish support systems to help student's embrace metacognitive learning. Initiatives like peer mentoring, tutoring, or counseling sessions can guide students in developing self-regulated learning habits and addressing challenges they face in applying these strategies.

4. Ongoing Research and Feedback: Conduct regular evaluations of how metacognitive strategies impact learning outcomes. Use this feedback to refine teaching methods and address barriers to implementation, ensuring the approach remains effective and inclusive.

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