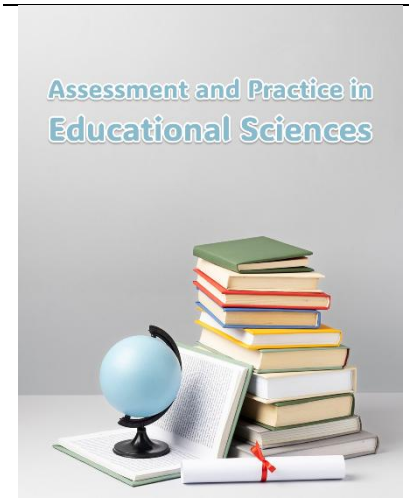
Assessment and Practice in Educational Sciences



Exploring Assessment Strategies Used to Promote Metacognitive Development in Science Education

ABSTRACT

This study aimed to explore the assessment strategies employed by secondary science educators in Tehran to promote metacognitive development among students. A qualitative research design was adopted, utilizing semi-structured interviews with 16 secondary science teachers selected through purposive sampling from various schools in Tehran. Data collection continued until theoretical saturation was achieved. All interviews were transcribed verbatim and analyzed using thematic analysis, supported by NVivo software, to identify recurring themes and subthemes related to metacognitive assessment practices. Analysis revealed three main themes: (1) assessment as a tool for reflection, including strategies such as self-monitoring, retrospective and predictive thinking, and structured feedback; (2) teacher roles in supporting metacognition, encompassing the design of metacognitive tasks, facilitation of dialogue, modeling reflective behavior, and creating a supportive assessment climate; and (3) student engagement with metacognition, involving ownership of learning, peer-based reflection, cognitive awareness, and the transfer of metacognitive strategies across tasks. Teachers reported using guided reflection sheets, think-alouds, self-assessment checklists, and collaborative discussions to foster metacognitive skills. Challenges included time constraints, curricular pressures, and balancing formative and summative assessment demands. The findings underscore the importance of intentional assessment design, teacher modeling, and supportive classroom environments in fostering metacognitive development in science education. While effective strategies are being implemented, systemic constraints limit broader adoption. Continued professional development and policy support are recommended to empower educators and prioritize metacognitive learning outcomes in science curricula.

Keywords: Metacognition; formative assessment; science education; teacher practices; student engagement; qualitative research; Iran.

1. Behnaz. Zarepour: Department of Educational Sciences, Kharazmi University, Tehran, Iran
2. Hamid. Soleimani*: Department of Sociology, Kharazmi University, Tehran, Iran.
(Email: h73.soleimani@gmail.com)
3. Mehrshad. Sanjari: Department of Educational Technology, Kharazmi University, Tehran, Iran

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Introduction

The increasing complexity of the modern world and the rapid advancement of scientific and technological knowledge have placed new demands on education systems worldwide. In particular, science education is now expected not only to transmit disciplinary content but also to foster the development of higher-order cognitive skills, such as critical thinking, problem-solving, and metacognition (National Research Council [NRC], 2012). Metacognition, defined as “thinking about one’s own thinking,” is widely recognized as a fundamental component of self-regulated learning and a key predictor of academic success in science domains (Schraw et al., 2006; Zohar & Barzilai, 2013). The development of metacognitive skills enables learners to

plan, monitor, and evaluate their own understanding and performance, equipping them to engage meaningfully with complex scientific concepts and to adapt flexibly to novel learning challenges (Pintrich, 2002; White & Frederiksen, 2005).

Despite its established importance, research indicates that metacognitive development does not occur automatically through content instruction alone; rather, it must be explicitly taught and intentionally embedded in classroom practices (Veenman, 2017). In the context of science education, metacognitive instruction has been linked to a range of positive outcomes, including increased conceptual understanding, improved problem-solving ability, greater resilience in the face of cognitive challenges, and enhanced transfer of knowledge to new situations (Cooper & Sandi-Urena, 2009; Zepeda et al., 2015). Accordingly, educational policy documents and curricular frameworks increasingly advocate for the integration of metacognitive strategies within science teaching and assessment (NRC, 2012; OECD, 2019).

Assessment practices play a crucial role in supporting and promoting metacognitive development in science classrooms. While traditional assessments have often focused on the recall of factual knowledge, there is growing recognition that assessment can also function as a powerful tool for scaffolding students' reflective thinking and self-regulation (Black & Wiliam, 2009; Shepard, 2019). Formative assessment, in particular, has been highlighted as a means to engage students in metacognitive processes by encouraging them to monitor their own understanding, reflect on their learning strategies, and adjust their approaches in response to feedback (Clark, 2012; Panadero et al., 2018). Through assessment tasks that require explanation, justification, and self-evaluation, students are prompted to make their thinking visible, confront misconceptions, and develop a more sophisticated awareness of their own cognitive processes (Baird & Mitchell, 2014; Nicol & Macfarlane-Dick, 2006).

The design and implementation of assessment strategies aimed at fostering metacognition are, however, far from straightforward. Teachers must balance curricular demands, high-stakes testing pressures, and diverse student needs while creating assessment opportunities that genuinely support metacognitive growth (Furtak et al., 2016). Furthermore, effective metacognitive assessment requires a shift in both teacher and student roles: teachers must move beyond simple transmission of knowledge to become facilitators of inquiry and reflection, while students must assume greater responsibility for their own learning (Hacker et al., 2009; Zohar & Barzilai, 2013). Empirical studies have identified various assessment approaches with potential to promote metacognitive development, such as self-assessment, peer assessment, think-aloud protocols, reflective journals, and structured feedback cycles (Butler, 2011; Panadero et al., 2016; White & Frederiksen, 2005). Yet, the extent to which these strategies are adopted in science classrooms, and the challenges encountered in their implementation, remain underexplored, particularly in non-Western contexts.

In Iran, as in many other countries, science education is increasingly recognized as critical to national development and global competitiveness (Mehran, 2016). Recent educational reforms have called for a greater emphasis on inquiry-based learning, student-centered pedagogy, and the development of transferable thinking skills (Sadeghi & Richards, 2015). However, research suggests that prevailing assessment practices in Iranian schools often remain dominated by summative examinations and teacher-centered approaches, with limited opportunities for students to engage in reflective or metacognitive processes (Rezaei & Bagheri, 2015; Sajjadi et al., 2020). Teachers face considerable challenges in adopting formative and metacognitive assessment strategies, including large class sizes, time constraints, and a lack of professional development focused on these areas (Ahmadi et al., 2021). Consequently, there is a pressing need to investigate how science teachers in Iran conceptualize and utilize assessment strategies to support metacognitive development, and to identify effective practices and barriers in this context.

Globally, the literature underscores the value of explicit metacognitive instruction and assessment in science education. For example, Zepeda et al. (2015) found that interventions incorporating metacognitive prompts and self-explanation tasks led to

significant gains in students' ability to regulate their learning and improve conceptual understanding. Similarly, White and Frederiksen (2005) demonstrated that the use of reflective assessment cycles, where students regularly analyzed their thinking processes and outcomes, resulted in higher science achievement and more sophisticated problem-solving. Panadero et al. (2016) highlighted the effectiveness of self-assessment and peer assessment as metacognitive tools, showing that such practices enhance students' ability to monitor and adjust their learning strategies. Importantly, these studies emphasize the need for assessment practices to be integrated with classroom instruction and to be responsive to the unique cultural and institutional contexts in which they are implemented.

The role of teachers is pivotal in mediating the relationship between assessment and metacognitive development. Teachers' beliefs, knowledge, and pedagogical skills shape the extent to which assessment tasks foster reflection, self-monitoring, and strategy use (Brown & Harris, 2013). Research has shown that teachers who model metacognitive thinking, provide targeted feedback, and create a supportive classroom climate can significantly enhance students' metacognitive awareness and engagement (Shepard, 2019; Veenman, 2017). Conversely, when assessment is used primarily for grading or accountability, opportunities for metacognitive growth may be limited. Understanding the lived experiences and practical strategies of teachers is therefore essential for advancing metacognitive assessment in science education.

In summary, the promotion of metacognitive skills is a central goal of contemporary science education, with assessment serving as a key lever for supporting this objective. Despite growing recognition of its importance, the integration of metacognitive assessment strategies in classroom practice remains uneven, and there is a need for more nuanced, context-specific research to inform policy and teacher development (Clark, 2012; Zohar & Barzilai, 2013). This study addresses this gap by qualitatively exploring the assessment strategies used by secondary science teachers in Tehran to promote metacognitive development. By investigating teachers' beliefs, practices, and perceived challenges, the research seeks to contribute to a deeper understanding of how assessment can be harnessed to foster reflective, self-regulated learners in science classrooms. Ultimately, the findings aim to inform both local and international efforts to enhance science education through effective, metacognitively-oriented assessment practices.

Methods and Materials

Study Design and Participants

This study adopted a qualitative research design with an exploratory approach, aiming to gain in-depth insights into how assessment strategies are utilized to foster metacognitive development in science education. Qualitative inquiry was deemed appropriate due to its capacity to explore complex, context-bound educational phenomena from the perspectives of those directly involved. The research employed semi-structured interviews as the primary data collection method, enabling the elicitation of rich, nuanced responses from participants regarding their experiences, beliefs, and instructional practices.

The participants consisted of 16 secondary science educators working in various public and private schools across Tehran. Purposeful sampling was used to select participants with relevant teaching experience and demonstrable interest in applying metacognitive strategies in their assessment practices. Teachers were selected to reflect a diversity of backgrounds in terms of teaching experience (ranging from 5 to 25 years), school settings, and subjects taught (e.g., biology, physics, chemistry). Participation was voluntary, and all participants provided informed consent prior to data collection.

Data Collection

Data were collected through individual, semi-structured interviews, conducted face-to-face or via secure video conferencing platforms, depending on participants' availability and preferences. The interview protocol consisted of open-ended questions designed to explore the participants' understanding of metacognition, the assessment strategies they employed to support metacognitive development, challenges faced, and perceived outcomes in student learning. Follow-up and probing questions were used as needed to deepen the responses and clarify ambiguities.

Each interview lasted approximately 45 to 60 minutes and was audio-recorded with the participants' permission. Interviews were conducted in Persian and transcribed verbatim to ensure accuracy. To maintain confidentiality, pseudonyms were assigned to all participants, and identifying information was removed from transcripts.

The process of data collection continued until theoretical saturation was achieved—that is, the point at which no new themes or significant insights emerged from the data. Saturation was reached after interviewing 16 participants, ensuring the depth and adequacy of the data for subsequent analysis.

Data analysis

Thematic analysis was employed to analyze the data, following Braun and Clarke's (2006) six-step framework: familiarization with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. The transcribed interviews were first read multiple times to gain a holistic understanding of the content. Open coding was then conducted to identify key concepts, recurring patterns, and meaningful segments related to assessment practices and metacognitive development.

Data analysis was supported using NVivo software, which facilitated systematic organization, coding, and retrieval of textual data. Codes were iteratively refined through constant comparison across interviews. Emerging categories and themes were discussed among the research team to enhance reliability and reduce subjective bias. Reflexivity was maintained throughout the process, with the researchers keeping analytic memos and documenting their interpretations and decisions.

To ensure trustworthiness, the study adhered to Lincoln and Guba's (1985) criteria of credibility, transferability, dependability, and confirmability. Member checking was conducted by sharing summarized interpretations with several participants to confirm accuracy. Triangulation was achieved through peer debriefing and collaborative coding discussions among researchers.

Findings and Results

1. Assessment as a Tool for Reflection

One central finding was the deliberate use of assessment to encourage student self-monitoring. Teachers implemented strategies such as prompting students to ask themselves reflective questions, identify errors during tasks, plan necessary revisions, and engage in real-time reflection while learning. As one teacher shared, "When my students check their answers and find their mistakes themselves, I see them learning not just the content, but how to think about their own thinking."

Another prominent subtheme was prompting retrospective thinking. Many educators asked students to analyze their performance at the end of lessons or tasks, often through journaling or structured review prompts. Some utilized exit tickets to prompt students to articulate what they learned and what confused them. A participant noted, "I always ask students to write one thing they understood well and one thing they are still unsure about. This habit makes them revisit their process."

A third important approach was fostering predictive thinking through assessment. Teachers encouraged students to set learning goals, generate hypotheses before experiments, and anticipate possible outcomes. This practice aimed to prime students for intentional engagement. As expressed by a participant: “Before every lab, I ask, ‘What do you expect to happen?’ That question pushes them to plan and prepares them for deeper analysis later.”

The use of feedback to guide reflection was also integral. Teachers provided formative and descriptive feedback, maintained student feedback logs, and explicitly clarified misunderstandings in student work. This feedback was intentionally crafted to prompt students to think about their learning process, not just their results. One interviewee described: “My feedback is less about right or wrong and more about ‘how did you arrive here?’ This encourages students to rethink their approach.”

Finally, teachers described structuring reflection activities by integrating tools such as reflection sheets, guided questions, peer discussion prompts, and even visual timelines for mapping learning journeys. Such structures scaffolded students’ metacognitive engagement. “We use guided reflection sheets after each project. It’s amazing how their answers become more thoughtful over the term,” remarked one teacher.

2. Teacher Roles in Supporting Metacognition

A key dimension of teacher practice was designing metacognitive tasks. Educators intentionally included problem-based learning, concept mapping, and inquiry cycles, while embedding pre-assessment thinking routines to activate prior knowledge. These activities provided opportunities for students to plan, monitor, and evaluate their learning. As one teacher put it, “Problem-based tasks make students think through their steps before and after they work, and that’s where real growth happens.”

The theme of facilitating dialogue and verbalization was frequently discussed. Teachers used think-aloud protocols, group discussions, Socratic questioning, and paired explanations to externalize students’ thought processes. These interactions enabled students to verbalize their reasoning and compare strategies. “When students explain their thinking to peers, gaps in understanding become visible. Sometimes they catch their own mistakes just by talking it through,” an interviewee observed.

Another crucial subtheme was creating a safe assessment climate. Teachers sought to foster an environment where errors were accepted, test anxiety was reduced, exploration was encouraged, and feedback was delivered with a constructive tone. “I tell them it’s okay to make mistakes here. We’re learning together,” one teacher emphasized, reflecting a shared belief that emotional safety is foundational for metacognitive development.

Monitoring and adjusting instruction based on assessment evidence was described as an ongoing practice. Teachers regularly used assessment data to pace lessons, scaffold learning in real time, and adjust task difficulty. As described by a participant: “Sometimes, I notice several students struggling on the same question, so I pause and model my thought process or simplify the next task.”

The final teacher-focused subtheme was modeling metacognitive behavior. Educators demonstrated self-questioning, shared their own reflections, and modeled metacognitive strategies in class. “I make it a point to say out loud when I’m unsure and how I figure things out. That way, students see thinking as a process, not a product,” said one teacher.

3. Student Engagement with Metacognition

Ownership of learning emerged as a strong subtheme among students. Tools such as self-assessment checklists, progress trackers, reflection journals, and independent goal-setting were cited as empowering students to take charge of their own learning journey. “When students set their own goals and monitor progress, they become more motivated and focused,” a teacher shared.

A related finding was the impact of peer-based reflection. Structured peer review protocols, feedback swaps, group reflections, and co-assessment practices allowed students to gain insights from classmates, enhancing both self- and peer-

awareness. One participant observed, “Group reflections help students see that others struggle too, and sometimes peers explain things better than I can.”

Awareness of cognitive processes was another notable area. Teachers reported that students who recognized confusion, could label their own strategies, and understood the link between effort and outcomes developed stronger metacognitive abilities. “I ask them to say when they get stuck and what they try next. This helps them see learning as something they control,” one educator noted.

Metacognition was also observed to transfer across tasks. Teachers reported students applying strategies learned in one context (e.g., summarizing or predicting) to new topics or linking learning experiences across the curriculum. “After learning to reflect in biology, some students started doing it in math as well,” explained a participant.

Another subtheme was the role of motivation in metacognitive use. Teachers intentionally used confidence-boosting feedback, growth mindset language, and interest-driven assessment to encourage students to take risks and persist in their learning. “I tell them it’s not about being perfect, but about getting better each time,” a teacher said, highlighting the motivational underpinnings of metacognitive practice.

Finally, the subtheme of developing self-questioning routines was recurrent in interviews. Students were encouraged to regularly ask themselves, “What did I learn?”, “What could I do differently?”, and “Why did I think that?” to scaffold deeper self-reflection. As one participant remarked, “Simple questions, asked often, really change how students see their own learning.”

Discussion and Conclusion

The present study sought to explore the assessment strategies employed by secondary science educators in Tehran to promote metacognitive development among their students. Through a qualitative analysis of semi-structured interviews, several key themes emerged, highlighting the intentional and multifaceted role of assessment in fostering students’ metacognitive skills. The findings provide nuanced insight into how teachers design reflective assessment experiences, the pedagogical moves they make to support metacognitive engagement, and the ways in which students participate in and benefit from these practices.

One of the central findings was the use of assessment as a deliberate tool for reflection. Teachers described employing a variety of strategies—such as encouraging student self-monitoring, prompting retrospective thinking, and fostering predictive thinking—to engage students in metacognitive processes. Activities such as self-questioning, error identification, goal-setting, and hypothesis generation were commonly reported as integral elements of formative assessment practices. These strategies were further supported through the provision of descriptive feedback and the structuring of reflection activities, such as guided reflection sheets and peer discussions. This finding is consistent with previous research, which has emphasized the importance of assessment in making students’ thinking visible and scaffolding their self-regulation (Nicol & Macfarlane-Dick, 2006; Panadero et al., 2018). The intentional use of feedback to stimulate reflective thought aligns with Black and Wiliam’s (2009) assertion that formative assessment, when thoughtfully implemented, becomes a vehicle for metacognitive growth.

Another prominent theme related to the teacher’s role in supporting metacognitive development through assessment. Teachers in this study not only designed metacognitive tasks—such as problem-based learning, concept mapping, and inquiry cycles—but also facilitated dialogue and verbalization via think-alouds, group discussions, and Socratic questioning. By creating a safe assessment climate that valued mistakes and reduced anxiety, educators modeled metacognitive behaviors themselves and encouraged similar openness among their students. These findings mirror the conclusions of Baird and Mitchell (2014) and Veenman (2017), who highlight the crucial role of teachers in shaping classroom norms, providing cognitive modeling, and establishing the trust necessary for authentic reflection. The significance of teacher modeling, as noted in the

interviews, supports White and Frederiksen's (2005) suggestion that students benefit when they observe metacognitive thinking in action, gaining practical strategies they can adopt and adapt.

The study also illuminated the ways students engage with metacognition through assessment. Ownership of learning emerged as a central subtheme, with students utilizing self-assessment checklists, progress trackers, and goal-setting routines to monitor and direct their learning. Peer-based reflection and co-assessment activities provided further opportunities for students to compare strategies, gain new perspectives, and build self-awareness. Participants noted that these experiences contributed to a greater awareness of cognitive processes and facilitated the transfer of metacognitive strategies across topics and disciplines. This finding is corroborated by Panadero et al. (2016) and Brown and Harris (2013), who demonstrate that self- and peer-assessment not only enhance metacognitive skills but also promote greater learner autonomy and motivation. The integration of regular self-questioning routines, as reported by teachers, echoes the work of Schraw et al. (2006) and Zohar and Barzilai (2013), who advocate for explicit metacognitive instruction as a means to deepen students' understanding and foster independent learning.

The data further reveal that the effectiveness of metacognitive assessment strategies depends on the broader educational environment, including institutional constraints, classroom culture, and teacher beliefs. Several teachers highlighted challenges related to time constraints, curricular demands, and the prevalence of high-stakes summative assessment, which often limit the depth and frequency of reflective practices. This tension between formative and summative assessment priorities is well-documented in the literature (Furtak et al., 2016; Shepard, 2019). Despite these obstacles, the participants in this study expressed a strong commitment to cultivating metacognitive skills, employing creative adaptations and advocating for a gradual shift toward more student-centered assessment paradigms. Their experiences resonate with findings from Iranian and international contexts that underscore the importance of professional development and systemic support for meaningful assessment reform (Ahmadi et al., 2021; Rezaei & Bagheri, 2015).

In light of these findings, this study contributes to a growing body of evidence supporting the centrality of assessment in metacognitive development within science education. The data illustrate that effective metacognitive assessment is not the product of isolated interventions, but rather emerges from a constellation of interconnected practices—feedback, reflection, modeling, and student engagement—all underpinned by intentional teacher design and a supportive classroom climate. This holistic perspective is reflected in the frameworks proposed by Clark (2012) and Panadero et al. (2018), who argue that the integration of formative assessment with metacognitive scaffolding produces synergistic effects on student learning outcomes. Moreover, the cultural and contextual nuances captured in this study underscore the need for flexible and adaptive assessment models that are responsive to the realities of local classrooms.

Taken together, the results suggest that while challenges persist, there is significant potential for teachers to use assessment as a lever for fostering metacognitive growth in science classrooms. The reported practices—including structured reflection, dialogic feedback, collaborative assessment, and teacher modeling—align with international best practices and have demonstrated positive impacts on student motivation, resilience, and conceptual understanding (Zepeda et al., 2015; Shepard, 2019). These findings reinforce the imperative for educational leaders and policymakers to support ongoing teacher development, facilitate the sharing of effective strategies, and reimagine assessment policies to prioritize metacognitive learning as a central outcome of science education.

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Authors' Contributions

All authors equally contributed to this study.

Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

All ethical principles were adheried in conducting and writing this article.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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