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Regulating the Load: A Systematic Review of SRL and Metacognitive Strategies in STEM Problem Solving Tasks

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Abstract

This systematic review examines how students manage cognitive load during STEM problem solving by using self-regulated learning (SRL) and metacognitive strategies, and how instructional designs can support these attempts. Fourteen empirical studies published since 2010 were thematically analyzed using the SALSA framework and PRISMA guidelines. Based on these studies, the findings suggest that SRL strategies do more than reducing the cognitive load and they also facilitate deeper student engagement by increasing germane cognitive load. The findings are organized according to two research questions. The first focuses on the strategies students use to reduce the cognitive load, which emerge under three themes as "Monitoring & "Evaluation", "Elaboration & Explanation", and "Strategic Regulation". The second focuses on how instructional designs support these strategies particularly through "Metacognitive Activation via Prompting" and "Load Optimization through Multimedia Principles". Overall, the findings reveal that when students are encouraged to reflect, explain, and make conscious choices regarding their existing skills and knowledge, they can better handle the cognitive load of complex STEM tasks. Instructional supports like prompts and multimedia elements help to reduce extraneous load and create space for meaningful learning. These results point to the value of flexible, well-designed learning environments that actively support students in managing their thinking processes.

Introduction

Cognitive load refers to the mental effort that required to process information in working memory (Sweller, 1988). As learners construct schemas, the information becomes more organized, which helps them to perform familiar tasks with less conscious effort. This process which is known as schema automation frees up working memory resources and allows learners to handle new information more efficiently (Sweller et al., 1998). Cognitive load is divided into three types as intrinsic, extraneous, and germane (Sweller et al., 1998). Intrinsic cognitive load is about to the inherent complexity of the material. In contrast, extraneous load comes from poorly designed instructional materials and should be minimized. Germane cognitive load represents the effort dedicated to building and automating schemas, which directly enhances learning.

Due to the inherent complexity of STEM subjects, students' short-term memories experience a a high cognitive load. (Maj, 2020). When this intrinsic cognitive load becomes too high, it can hinder both retention and comprehension which makes it difficult for students to understand and retain new information (Maj, 2020). Especially problem solving in STEM subjects which contain complex ideas, symbols, and multiple steps increases the chance of mistakes because of this high cognitive load (Cardellini, 2014).

Problem solving itself is a cognitive process that involves many intertwined components, such as perception, attention, memory, and thinking (Li et al., 2022). When learners engage in intellectual activities like problem solving, their working memory generally become overloaded (Sweller et al., 1998). This makes it significant for them to have well-developed schemas related to these tasks so they can better manage the cognitive demands involved (Sweller et al., 1998). This requires to decrease the extraneous and increasing the germane load.

During problem solving, students usually need to go through several steps like comprehending the problem, choosing which formulas to use, organizing and carrying out a solution, and then verifying their answers which naturally brings high cognitive demands (Santiago et al., 2024. However, a significant number of STEM students rely on rote memorization without really comprehending the underlying concepts which prevents them from learning in a meaningful way over the long term and results in "pseudo-understanding," which is a sign of poorly managed cognitive load (Mariano et al., 2017).

As a solution, to effectively regulate these mental activities, planning, monitoring, and evaluation, as central elements of metacognition, have been shown to play a critical role in problem-solving success (Fiteriani et al., 2021). To increase students' awareness of cognitive processes, encouraging them to use metacognitive strategies to plan, monitor, and assess their own learning helps them organize their ideas and take a more strategic approach to problems (Mariano et al., 2017). Moreover, germane cognitive load which is about to the construction and automation of schemas, is closely linked to metacognitive processes and problem solving (Ayvaz-Tuncel & Demir, 2024). Metacognitive skills are crucial since they increase germane load and decrease extraneous load, which makes problem solving more efficient (Ayvaz-Tuncel & Demir, 2024). This shows why developing SRL and metacognitive strategies should be taken into account when it comes to managing cognitive load. In this regard, metacognitive skills like strategy selection, behavioral adjustment, and monitoring which are core aspects of self-regulated learning (SRL) are very essential (Li et al., 2022).

Nowadays, the rising need for learner autonomy and the cognitive difficulties presented in complex learning environments made self-regulated learning (SRL) and its role of managing cognitive load increasingly significant (de Bruin et al., 2020). The current literature highlights a significant gap in understanding the dynamic relationship between SRL strategies and cognitive load patterns (Gorbunova et al., 2024). The recent literature questions whether self-regulated learning (SRL) increases cognitive load due to extra metacognitive requirements or diminishes it by supporting more efficient processing (Wang et al., 2024). Although strong self-regulation skills can reduce extraneous cognitive load from poorly designed materials, prolonged learning durations can also decrease self-control which results in raising cognitive load and hindering learning (Eitel et al., 2020). The relationship between self-regulated learning (SRL) and cognitive load is reciprocal (de Bruin et al., 2025): SRL influences cognitive load via strategy use and effort management, while cognitive load also influences the effectiveness of SRL processes (Seufert, 2020; de Bruin et al., 2020). When cognitive load exceeds working memory capacity, learners may be lacking in the mental resources required for planning, monitoring, and regulating their self-regulated learning (SRL). Consequently, SRL strategies may become inadequate. On the other hand, when students experience increased cognitive load, they may interpret it as “I cannot learn this” (effort perceived as pointless) and consequently limit their application of self-regulated learning strategies.

Although the relationship between self-regulated learning (SRL) and cognitive load (CL) has been studied in education, most of the existing researches approach this topic through broad theoretical models or general associations. For example, Seufert et al. (2024) and Gorbunova et al. (2024) examined the relationships between SRL skills, cognitive load, and performance in general learning contexts, while Wirth et al. (2020) and de Bruin et al. (2020) provided a theoretical explanation of the interaction between SRL and cognitive load. The relationship between SRL behavior patterns and problem-solving performance has been studied by Li et al. (2023), Borchers et al. (2024), and Wang et al. (2024). However, most of this studies do not specifically address STEM subjects, nor does it describe the specific SRL and metacognitive strategies that students use to cope with various forms of cognitive load when completing challenging STEM problem-solving exercises. Furthermore, they do not category these strategies into themes for different ages or instructional designs.

This systematic review aims to fill that gap by showing how students use and adjust SRL and metacognitive strategies to manage cognitive load in STEM problem-solving, and by highlighting how instructional designs support these self-regulatory processes. In line with this, the main goal of this study is to systematically investigate the specific self-regulated learning and metacognitive strategies that learners use to manage different types of cognitive load during STEM problem-solving tasks, and how instructional designs facilitate these processes, based on empirical studies published since 2010.

To reach this aim, the study seeks to answer the following research questions:

1. In STEM problem-solving contexts, what SRL and metacognitive strategies do learners use to manage cognitive load?
2. How do instructional designs facilitate learners’ cognitive load management by promoting SRL and metacognitive strategies?

Method

Research Design

This study was designed as a systematic literature review (SLR) to explore how SRL and metacognitive strategies used in managing cognitive load during STEM problem solving tasks and how instructional designs facilitate learners’ cognitive load management by promoting SRL and metacognitive strategies. The framework was based on the SALSA methodology proposed by Booth et al. (2016) that separates the review process into four stages as

Search, Appraisal, Synthesis, and Analysis.

Search involves systematically searching databases for related studies. Then, appraisal step refers to examining the selected studies based on inclusion and exclusion criteria and assessing their quality. Synthesis step organizes and categorizes findings qualitatively. Lastly, Analysis looks for deeper patterns and identifies research gaps. To ensure transparency and reproducibility, the review followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. A PRISMA flow diagram was used to document study selection (Moher et al., 2009).

Databases and Search Strategy

The database search was completed in July 2025, using three major academic databases:

- EBSCO
- Web of Science
- Scopus

To keep the focus on more recent work, the search was limited to journal articles published in English from 2010 onwards. The keywords were combined in the following way:

("self-regulated learning" OR "SRL" OR "metacognition" OR "self-monitoring")
AND ("physics" OR "engineering" OR "problem solving")
AND ("cognitive offloading" OR "cognitive load")

This search turned up:

- 16 articles in EBSCO,
- 44 in Web of Science, and
- 24 in Scopus.

Eligibility Criteria and Screening

Totally 84 records were imported into Zotero for reference management and the elimination of duplicates. After the removal of 19 duplicate entries, 65 distinct articles remained. Titles and abstracts were evaluated according to the inclusion criteria, and complete texts which were available were obtained. Access problems limited the acquisition of 11 papers which resulted in 54 studies available for detailed evaluation. During this examination, the studies were included if they:

1. Reported empirical research (quantitative, qualitative, or mixed-method),
2. Involved students at the middle school, high school, or university level,
3. Focused on problem-solving tasks in STEM disciplines (physics, mathematics, biology, or engineering),
4. Addressed both SRL/metacognitive strategies and cognitive load management.

Following full-text screening, 17 studies met these criteria.

Study Selection and Data Extraction

Among the 17 studies included in the qualitative synthesis, only 14 provided detailed empirical evidence on the relationship between SRL/metacognition and cognitive load in STEM problem-solving. These were selected for in-depth thematic analysis. A closer analysis identified 14 studies that provided clear insights into the relationship between SRL or metacognition and cognitive load, which were then selected for in-depth synthesis. A single researcher conducted the screening and selection process, guided by a clear coding scheme to minimize bias. In cases of uncertainty, abstracts and, when needed, full texts were revisited.

Synthesis and Analysis

Using the constant comparative method, thematic synthesis was conducted to find and group the SRL and metacognitive strategies used for managing cognitive load. This method involves constantly looking at the data to detect patterns and themes that come up repeatedly, and then comparing these findings to show how they are different and how they are related (Merriam, 1998). Although the thematic coding was conducted by a single researcher, different strategies were employed to increase credibility. These are engaging in reflexive coding, and consulting an expert in educational research for theme validation. This approach helped mitigate subjectivity and strengthened the trustworthiness of the synthesis.

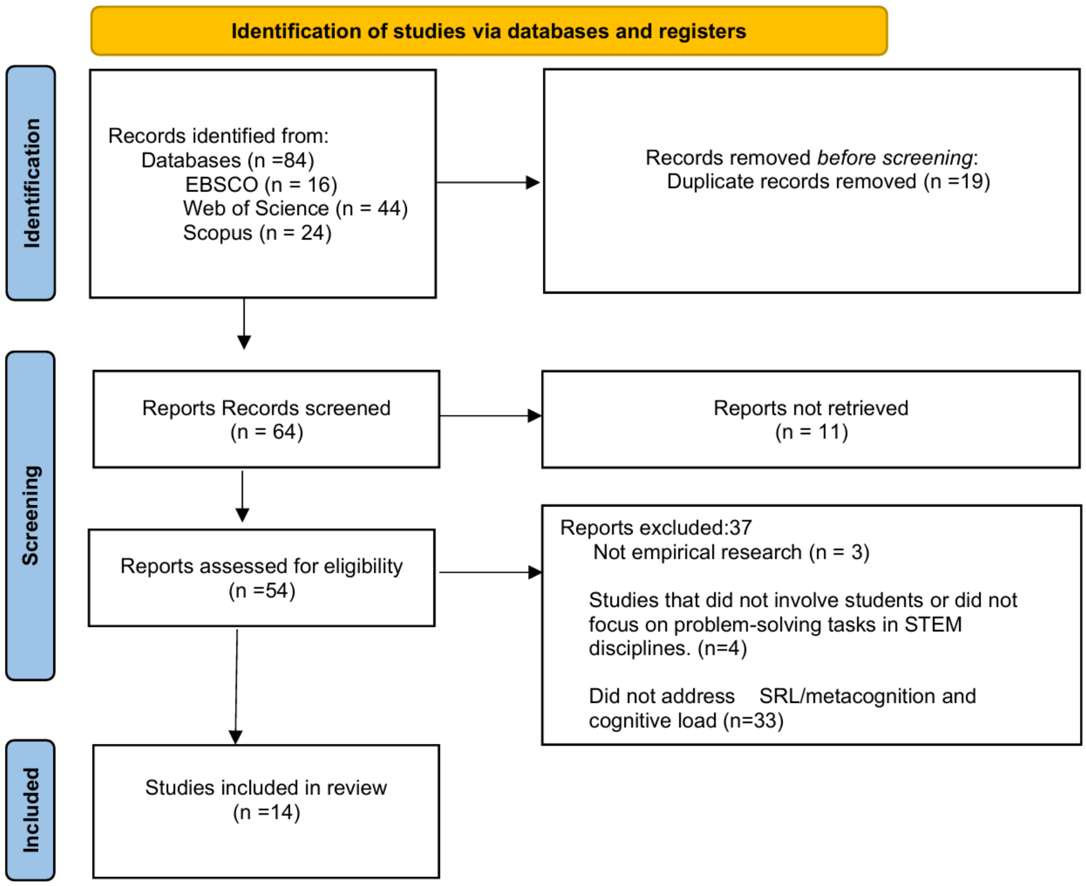

Figure 1. PRISMA Flow Diagram Illustrating the Study Selection Process

Before laying out of thematic findings, Table 1 offers a summary of the empirical research included in this review. It includes key characteristics including the country, participant age or level of education, and the STEM problem domains addressed. The table shows that the majority of research were conducted with university-level students, with only a limited number involving participants from secondary or middle school. It is crucial to consider this distribution when interpreting the scope and generalizability of the review's findings.

Table 1.Overview of the Included Studies

Citation	Country	Age / Grade	Problem Domain
Baars et al. (2013)	Netherlands	9^{th} grade students (ages 14–15)	Biology
Baars et al. (2018)	Netherlands & Germany	Secondary school students (ages 12–15)	Biology
Foster et al. (2018)	USA	University freshmen (M ≈ 19.5 years)	Mathematics
van Harsel et al. (2022)	Netherlands	Higher education students (M ≈ 19 years)	Mathematics
Lindner (2020)	Germany	5^{th}–6^{th} grade students (M ≈ 11.4 years)	Science & Math
Morphew et al. (2020)	USA	University students	Physics
Gök et al. (2024)	USA	Undergraduate students (ages 17–24, M ≈ 19.3 years)	Mathematics
Kang et al. (2023)	China	6^{th} grade students (M ≈ 11.4 years)	Mathematics
Moser et al. (2017)	Austria	Secondary school students (M ≈ 13.2 years)	Physics
McClellan et al. (2024)	USA	Undergraduate students (M ≈ 19.1 years)	Physics
Graham et al. (2024)	Netherlands	University students (ages 18–25, M ≈ 20.1 years)	Biology
Holmes (2014)	USA	University students (mostly 2^{nd}-year students)	Electrical engineering
Mihalca et al. (2017)	Germany	University students (M ≈ 23.1 years)	Genetics
Lui et al. (2019)	Hong Kong	University students	Computer algorithms

Results

This section reports the findings which are organized around two main research questions. A detailed analysis of 14 studies showed two complementary perspectives on managing cognitive load during problem solving. Under the first research question that focused on how learners regulate their cognitive load using SRL and metacognitive strategies three themes emerged which are: Monitoring & Evaluation, Elaboration & Explanation, and Strategic Regulation. The second research question which explored how instructional environments facilitate this process, had two themes which are Metacognitive Activation through Prompting and Load Optimization via Multimedia Principles. Table 1 provides an overview of the studies aligned with each question and thematic category.

Table 2. Summary of themes and studies

Research Question	Theme	Citation
In STEM problem-solving contexts, what SRL and metacognitive strategies do learners use to manage cognitive load?	Monitoring & Evaluation	Baars et al. (2013)
		Foster et al. (2018)
		Graham et al. (2024)
		Morphew et al. (2020)
		Mihalca et al. (2017)
		Holmes (2014)
	Elaboration & Explanation	Baars et al. (2018)
		Baars et al. (2013)
		Graham et al. (2024)
	Strategic Regulation	van Harsel et al. (2022)
		Graham et al. (2024)
		Foster et al. (2018)
		Morphew et al. (2020)
		Lui et al. (2019)
		Mihalca et al. (2017)
		Holmes (2014)
How do instructional designs facilitate or scaffold learners' cognitive load management and strategic regulation?	Metacognitive Activation via Prompting	Kang et al. (2023)
		Moser et al. (2017)
		McClellan et al. (2024)
		Graham et al. (2024)
	Load Optimization through Multimedia Principles	van Harsel et al. (2022)
		Baars et al. (2013)
		Morphew et al. (2020)
		Mihalca et al. (2017)
		Lindner (2020)
		Gök et al. (2024)

How do learners manage cognitive load using SRL and metacognitive strategies?

Monitoring & Evaluation

This theme explains how students monitor their own learning processes and how they use the results of this monitoring to adjust their learning strategies. Monitoring, as a core component of self-regulated learning (SRL), helps learners evaluate their current knowledge and make necessary adjustments to reach their goals (Baars et al., 2013; Foster et al., 2018). Students frequently employ metacognitive techniques like Self-Assessments (SAs) or Judgments of Learning (JOLs) to track their progress while solving problems (Baars et al., 2018; Graham et al., 2024).

The accuracy of this monitoring which means a student's ability to make correct predictions about their own learning is essential for effective self-regulation. However, students typically overestimate their understanding and frequently rely on weak indicators like fluency or familiarity. This leads to issues such as the illusion of understanding or overconfidence (Morphew et al., 2020; Baars et al., 2018). These inaccurate judgments can cause students to mismanage cognitive load and learn less effectively.

Another element that influences students' monitoring accuracy is task complexity. Students find it more difficult to correctly interpret JOL cues as a result of more difficult assignments which challenge their cognitive abilities. Judgments made during complex problems are often less accurate than those made during simpler tasks (Baars et al., 2018; Graham et al., 2024).

How well a student monitors their learning is also influenced by their level of prior knowledge. According to Mihalca et al. (2017), those who have more prior knowledge usually make more accurate judgments (Mihalca et al., 2017). Still, it's important to note that the act of monitoring itself can increase cognitive load. According to some studies, monitoring doesn't always result in more cognitive load, and in some cases, it leads to strategic adjustments that reduce the load.

It has also been observed that students test their own competence by attempting problems first, and when they struggle, they turn to worked examples. This continuous process shows how learning can be guided by monitoring and evaluation strategies (Foster et al., 2018). Students usually employ more examples which is a sign of strategic adjustment based on monitoring especially after making errors.

In sum, students' ability to monitor and evaluate their learning plays a key role in managing cognitive load and achieving deeper learning. However, their monitoring judgments must be accurate for these strategies to work. As a result, instructional designs should include tools that help students in more accurately calibrating their judgments in while providing opportunities for them to monitor their learning.

Elaboration & Explanation

This theme focuses on how learners make use of strategies such as self-explanation and think-aloud during problem-solving to articulate their acquired knowledge. These strategies seek to enhance understanding and optimize the utilization of cognitive resources rather than simply memorizing information (Baars et al., 2013). In complex tasks like STEM problem-solving, elaborative strategies can help learners in effectively managing their cognitive load.

Self-explanation which is a strategy involves students explaining the processes of a problem using their own words. This strategy enables the integration of new information with pre-existing knowledge. Baars et al. (2018) discovered that self-explanations enhance both learning performance and the accuracy of monitoring. When students perform self-explanation, they commonly identify conflicts between their mental models and the presented situation and by resolving these conflicts, they develop their conceptual knowledge.

Baars et al. (2013) showed that using organized strategies, such as developing concept maps or generating keywords, improves monitoring accuracy. These methods provide more valid and dependable indicators regarding the quality of learners comprehension. This enables them to more effectively identify their actual learning and the areas where their knowledge is inadequate.

In conclusion, elaboration and explanation strategies are crucial in enhancing cognitive load management and facilitating meaningful learning. They assist students in focusing their cognitive resources on deep learning. The efficacy of these strategies is dependent on students' self-awareness and prior knowledge. Therefore, it is essential for educational settings to offer explicit instructions and illustrations on how to make effective use of these strategies.

Strategic Regulation

This theme focuses on how students consciously and proactively make decisions on their learning concerning what to study, when to study, and the duration of their study sessions. Strategic regulation, an essential element of self-regulated learning (SRL), includes goal setting, the selection and implementation of appropriate strategies, and an ongoing monitoring of one's progress (Graham et al., 2024; Mihalca et al., 2017). Students frequently dedicate additional time to subjects they perceive more challenging or unfamiliar (Mihalca et al., 2017). Nonetheless, just an allocation of time does not ensure learning. The critical factor is the strategic utilization of time and its alignment with cognitive resources.

Another facet of strategic regulation involves choosing between solving problems or initially studying worked examples. In a study conducted by Van Harsel et al. (2022), students showed a preference for starting the process with problems-solving tasks when provided the freedom to select among various task types. However, this is not always optimum, since research indicates that students often neglect evidence-based procedures such as Worked-Example Problem Solving (WEPS) (Foster et al., 2018).

Foster et al. (2018) discovered that students showed enhanced self-regulation when confronted with partially worked-out problems. These activities prompted students to assess their existing knowledge and complete the missing steps foster strategic thinking. Morphew et al. (2020) showed that attempting a solution before examining the proper one can improve learning, especially for tasks that are slightly beyond a student's current capabilities. However too challenging tasks may result in overconfidence or frustration with this strategy.

Significant differences exist in strategic regulation between novice and expert learners. Studies conducted by Morphew et al. (2020) and Lui et al. (2019) indicates that high-achieving students effectively balance the utilization of examples and practice problems, while novices frequently split their attention ineffectively, resulting in high cognitive overload from extraneous information.

In conclusion, strategic regulation facilitates both cognitive load management and the enhancement of metacognitive awareness during the learning process. To be effective, instructional environments must be structured to assist students in balancing worked examples with problem-solving and in making deliberate choices regarding time management and task selection.

How do instructional designs facilitate or scaffold learners' cognitive load management and strategic regulation?

Metacognitive Activation via Prompting

This theme focuses on prompts which are formed to activate students' metacognitive processes during their learning. These systematic cognitive tools help to improve students' awareness of their thinking processes, allow for monitoring, and push them to change strategy when it is needed (Kang et al., 2023; McClellan et al., 2024). These support can prevent excessive repetitions in problem-solving and facilitate the optimal use of cognitive resources. Kang et al. (2023) reported that metacognitive prompts facilitated students' strategy changes, resulting in reducing unnecessary cognitive loops and reducing cognitive load during problem-solving. McClellan et al. (2024) showed that involving metacognitive questions into video lessons in a physics course increased students' attention and facilitated deeper cognitive processing. These cues can significantly reduce superfluous cognitive load in complex activities that results in enhancing the quality of learning.

Nevertheless, some studies indicate that metacognitive prompting does not always result in significant performance improvements, especially if prompts are limited to the cognitive level without contextual adaptation (McClellan et al., 2024). For optimal effectiveness, prompts must be modified to align with the content being learned and the students' levels of readiness. Cognitive cues, with metacognitive prompts, has significant potential for encouraging elaboration and regulation strategies. McClellan et al. (2024) observed that such prompts are especially beneficial for students who often employ disorganized or superficial strategies, since they facilitate the integration of new information with existing knowledge, the development of conceptual links, and the identification of important ideas.

In similar simulation-based learning environments, Moser et al. (2017) showed that metacognitive training, facilitated by prompts, improved students' use of planning, monitoring, evaluation, and self-questioning strategies. However, it is crucial to remember that such training may not always result in more positive outcomes. Graham et al. (2024) highlighted that think-aloud protocols are an effective strategy for showing students' self-monitoring behaviors and cognitive processes. Articulating their thoughts during tasks improves learners metacognitive awareness. Particularly, continuous monitoring instructions did not increase cognitive load, although they increased task completion time. Facilitating students' use of metacognitive prompts decreases cognitive load and fosters more strategic engagement with learning activities. These strategies can be especially beneficial for learners with limited self-regulation by providing essential scaffolding to facilitate their learning processes.

Load Optimization through Multimedia Principles

This theme focuses on how instructional environments designed according to multimedia principles can optimize students' cognitive load—especially during problem-solving. Multimedia-based instructional designs help reduce extraneous cognitive load, allowing learners to use their mental resources more efficiently, while also increasing germane cognitive load that contributes to schema construction. Instead of facing difficulties directly, students initially examine worked-out answers, facilitating the development of conceptual schemas (Gök et al., 2024; Morphew et al., 2020). This method eliminates unnecessary cognitive load and facilitates meaningful learning.

A related strategy called faded examples, guides learners from fully solved problems to partially completed and eventually unresolved problems. This gradual release improves independent problem-solving skills while scaffolding the learning process (van Harsel et al., 2022). Foster et al. (2018) showed that this type of approach resulted in better learning outcomes relative to standard worked examples. In the same way, completion problems, which ask students fill in missing steps, foster active participation and deeper processing. Baars et al. (2013) reported that these tasks can enhance monitoring accuracy.

Dynamic multimedia designs are essential for regulating cognitive load. Animated narrative solution videos (ANSVs) use visual and audio channels to focus attention, minimize extraneous cognitive load, and enhance student engagement with the material (Morphew et al., 2020). Videos developed according to Mayer's (2008) multimedia learning principles are particularly effective (Gök et al., 2024; Morphew et al., 2020). Multimedia feedback, involving both written and visual content, can support learning. Gök et al. (2024) discovered that visual representations help learners with evaluating their own performance. Representational pictures which shows the important elements of a topic, diminish cognitive load and improve comprehension (Lindner, 2020). Under the concept of learner control and adaptation, environments which allow students to choose the sequence, format, and duration of tasks offer more flexibility. However, this freedom can cause students to take bad decisions, especially if they have low prior knowledge or weak metacognitive skills (Mihalca et al., 2017). In such cases, it maty be better to limit learner control where students are required to complete specific tasks. This acts as a protective mechanism for learners with inaccurate monitoring judgments. Mihalca et al. (2017) emphasize that instructional design should be adapted based on students' monitoring accuracy.

Finally, automated task generators support self-regulated learning by providing worked examples and problem-solving exercises at varying difficulty levels (Lui et al., 2019). These systems can create an almost infinigte number of tasks and let students work at their own pace. As a result, multimedia-based instructional strategies not only help reduce cognitive load but also create space for learners to focus more on metacognitive strategies. This enables students to manage their learning processes in a more intentional and effective way.

Discussion

This systematic review revealed the variety of self-regulated learning (SRL) and metacognitive strategies that students use to manage cognitive load (CL) during STEM problem solving. Compared to earlier studies that mostly examined the relationship between SRL and CL through general theoretical models, this review provides more empirical evidence to the literature by categorizing these strategies and instructional design practices in STEM contexts. Although this review focused on combining research findings, connecting the results to well-known SRL theories can help us better understand why certain strategies work. For example, models such as Zimmerman's cycle (2000) and Winne and Hadwin's framework (1998) explain self-regulation as a series of steps which includes planning, monitoring, and reflection. These stages match with the themes emerged in this review, especially strategic regulation and self-monitoring. In addition, Wirth et al. (2020) point out that different stages of SRL are affected by different types of cognitive load. This shows that educators should pay attention to both the type of load and the stage of learning when designing instruction.

There is an ongoing discussion in the literature about whether SRL raises cognitive load due to its extra metacognitive demands or lowers it by promoting more efficient processing (Graham et al., 2024). While many analyses and syntheses (de Bruin et al., 2020; Seufert et al., 2024) often show SRL as a factor which reduces cognitive load, this review reveals that some SRL and metacognitive strategies not only reduce load but also intentionally increase germane load that supports schema construction. Considering the findings, SRL works not only as a way for load reduction, but also as a cognitive optimizer that strategically reallocates cognitive resources towards meaningful learning.

This finding aligns with current literature that highlights the need of both reducing extraneous load and actively redirecting cognitive effort (Sweller et al., 2019; de Bruin et al., 2025). For instance, effective strategies such as completion problems require that learners actively construct missing steps, which fosters deeper cognitive processing and provides students cues regarding their comprehension and success of their solution (Baars et al., 2013). While these strategies increase the germane load by directing cognitive effort on meaningful learning, they do not always result in higher test performance, as reported by Baars et al. (2013).

Furthermore, these findings also align with the EMR model (de Bruin et al., 2020), which highlights that learners' interpretations of effort may influence their self-regulation. When students view problems as a natural component of learning, they show higher perseverance and use feedback more effectively. Nevertheless, when effort is perceived as failure, learners may feel distracted or demoralized. Different perceptions of effort can influence the effectiveness of regulation strategies, making the quality of regulation as crucial as its existence.

The dual nature of regulation which is advantageous when applied effectively but challenging when misapplied underscores the necessity for carefully designed metacognitive support. Tools that match with students' needs and gradually guide them toward better decisions could be useful, especially for novices who often misjudge how difficult a task really is. In a study conducted by Morphew et al. (2020), students who tried to solve challenging problems before watching solution videos often overestimated their understanding. This illusion of understanding may cause students to terminate their study too early. Therefore, learners' perceptions of cognitive load (e.g., "I can't learn this" vs. "This feels hard because I'm learning something new") significantly influence SRL processes and cognitive load regulation. Considering the impact of these views on the quality of regulation, it is significant to know instructional strategies that can improve these judgments and direct students towards more effective self-regulation.

In addition to the SRL and metacognitive strategies which are preferred by learners to manage cognitive load, this study also focused on the instructional strategies that support learners in this regard. One of these strategies is

Metacognitive Activation via Prompting which includes metacognitive questions and self-questioning. This cannot directly lower the intrinsic load, but it can decrease the extraneous load by minimizing unnecessary processing pathways (Kang et al., 2023; Moser et al., 2017). Furthermore, it encourages learners to reflect on their areas of misunderstanding which facilitates the conscious development of schemas while additionally increasing the germane load. Especially in technologically enhanced environments where cognitive needs often exceed self-awareness, these supports are helpful. According to David et al. (2024), learners can interpret confusion as a sign of weakness rather than a need for adjustment and by providing prompts that normalize positive struggle, it is possible to reduce this misunderstanding and increase students' perseverance. These findings strongly correspond with general instructional design ideas, such as multimedia-based approaches, which, when integrated with metacognitive prompting, can improve cognitive load optimization.

Furthermore, the importance of instructional strategies that combine multimedia design and metacognitive prompting to increase germane load while reducing extraneous load is highlighted in Load Optimization via Multimedia Principles. By reducing split-attention, this strategy significantly decreases extraneous load and frees up working memory resources for schema formation (Mayer, 2005; Morphew et al., 2020; Gök et al., 2024). McClellan et al. (2024) indicated that these prompts are particularly helpful for fostering strategic regulating behaviors among learners with low self-regulated learning (SRL) skills. So, using multimedia resources and metacognitive questions together in lesson plans can more effectively enhance students' self-regulated learning skills. In addition to combining strategies, it is also critical to tailor them according to the needs of each learner where adaptive systems can play a transformative role.

Adaptive systems can provide personalized support for learners with low self-regulated learning (SRL). Considering these findings, instructional design needs to move from simply "reducing load" to "guiding load" in ways that enable students to self-direct. Instead of offering the same support to every student, these systems should adjust guidance based on real-time judgments, such as how difficult a task feels or whether the learner is making progress. This agrees with recent studies highlighting the necessity for more adaptable, learner sensitive educational designs (de Bruin et al., 2025). Foster et al. (2018) and Van Harsel et al. (2022) show that when students (especially novices) are allowed to select their own learning task formats, they sometimes exhibit well-regulated behavior, but also make suboptimal choices. For example, novices may continue choosing completion problems even after failing at them, believing that the format supports both learning and monitoring. These patterns suggest that the effectiveness of learner control is heavily influenced by students' metacognitive accuracy and prior expertise.

Van Harsel et al. (2022) observed that even though worked-example usage decreased over time in technical higher education students, they still preferred it in the early learning phase. Mihalca et al. (2017) found that the effectiveness of learner control is moderated by the accuracy of students' metacognitive judgments. Limiting learner autonomy which improved monitoring accuracy by reducing poor task selection helped students more. Weaker students require extra procedural scaffolding while more experienced students demonstrated better exploratory behavior and motivation, according to Lui et al. (2019). According to these findings, instructional design needs to be adapted regarding the expertise and metacognitive accuracy of the learners. Most of the evidence comes from studies with older students, but studies with younger students show that age-related changes may also affect how SRL strategies affect cognitive load. Baars et al. (2018) found that middle school students were less accurate at monitoring when they were tackling hard problems. Kang et al.(2023) found that elementary students experienced higher cognitive load during relatively simple number-sequencing tasks. These findings indicate that even when intrinsic load is relatively low, ineffective SRL strategy use can still raise extraneous load. Therefore, developmental differences in learners' cognitive and regulatory abilities should be taken into account when designing instructional supports.

Conclusion

This review shows that SRL strategies do more than just reduce cognitive load; they also help learners engage in meaningful cognitive effort and build strong mental models. Based on the findings, SRL can be seen as a cognitive optimizer instead of just a load reducer. Its dual role of lowering extraneous load and increasing germane load to support meaningful learning and schema development is highlighted. The findings have useful implications for instructional design and educational practice. instructional designers can more effectively direct cognitive load toward meaningful learning experiences by intentionally increasing germane cognitive load, rather than trying to eliminate it completely. SRL strategies should be viewed not only as ways of minimizing effort, but also as mechanisms to promote productive cognitive effort. Integrating monitoring and evaluation strategies into teaching such as guiding questions that prompt learners to compare their own solutions with expert models may enhance metacognitive accuracy.

Think-aloud and self-explanation strategies which help students to externalize and refine their thinking can also facilitate schema formation and should be promoted. Allowing students to choose tasks aligned with their current skill level, while gradually increasing complexity, can optimize intrinsic load and prevent the extraneous load caused by poor strategy choices. However, because the effectiveness of learner control may depend on metacognitive accuracy, restricted autonomy combined with scaffolding may be more effective for students who struggle to monitor their progress.

Metacognitive prompting, when combined with multimedia learning principles (Mayer, 2005), can reduce extraneous load and enhance attentional focus. Adaptive educational systems can provide students personalized SRL support by adjusting the guidance based on real-time performance monitoring. For students with low SRL skills, additional scaffolding such as structured feedback, example-based learning materials, and step-by-step guidance may be required.

Limitations

First of all, one of the crucial limitations of this review is that most of the included studies were conducted with university students (e.g., Baars et al., 2013; Foster et al., 2018; Graham et al., 2024; Lui et al., 2019; Mihalca et al., 2017; Morphew et al., 2020; Van Harsel et al., 2022; McClellan et al., 2024). Although these findings offer important perspectives for high-complexity problem-solving situations, their applicability to younger learners may be limited.

Most of samples consisted undergraduate students aged 18–25, with a limited number of research involving middle or secondary school students and very few focusing on early adolescents. Furthermore, most of interventions were either short-term or single-session which limits the comprehension of the long-term impacts of SRL strategies on schema building and cognitive load management.

Recommendations

Future research should investigate how SRL strategies work in younger populations, particularly in middle and high school settings where intrinsic load may be lower but ineffective strategy use can still raise extraneous load. Studies such as Baars et al. (2018) and Kang et al. (2023) indicate that developmental differences in cognitive and regulatory abilities affect how students manage load, highlighting the need for age-appropriate SRL supports that scaffold monitoring and task selection skills. Instructional design should not assume all students have the same and sufficient metacognitive awareness.

In addition to short-term interventions, further study should also investigate the long-term impacts of self-regulated learning strategies on schema development, cognitive load calibration, and learners' perceptions of effort. Longitudinal studies are vital for understanding how students' perceptions of cognitive effort (whether viewed as a sign of failure or as a sign of meaningful engagement) influence their persistence and learning outcomes over time. Understanding these mechanisms will be helpful for developing SRL supports that effectively strengthen learners' ability to manage cognitive load.

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