Vol 15 (1), 2026, 20-36 DOI: 10.23960/jppkv2.1513
Jurnal Pendidikan dan Pembelajaran Kimia
e-ISSN: 2714-9595| p-ISSN 2302-1772
http://jurnal.fkip.unila.ac.id/index.php/JPK/index

Instructional Approaches for Fostering Self-Regulated Learning in Chemistry Education: A Systematic Literature Review

Munawwarah[1*], Hastuti Agussalim[2]

Chemistry Education, Faculty of Mathematic and Natural Science, Universitas Negeri Makassar, Indonesia
Jl. Kampus UNM Parangtambung, Jl. Daeng Tata, Kecamatan Tamalate, Kota Makassar, Sulawesi Selatan, 90224

*Correspondinge-mail: [1]munawwarah@unm.ac.id, Hastuti.agussalim@unm.ac.id

Received: March 3rd, 2026 Accepted: March 12th, 2026 Online Published: April 30st, 2026

Abstract: *Instructional Approaches for Fostering Self-Regulated Learning in Chemistry Education: A Systematic Literature Review.* This study aims to identify and analyze instructional approaches used to foster self-regulated learning (SRL) in chemistry education through a systematic literature review (SLR). The review followed the PRISMA guidelines by initially collecting 100 articles from multiple academic databases, including Scopus, Web of Science, ERIC, and Google Scholar. After removing duplicates, 98 records remained and were screened based on titles and abstracts, resulting in 60 relevant studies. These articles were further assessed through full-text evaluation using predefined inclusion and exclusion criteria, leading to the final inclusion of 40 studies for analysis. The data were analyzed using a thematic synthesis approach to categorize instructional strategies and the SRL components they address. The findings reveal that instructional approaches in chemistry education can be classified into six main categories: metacognitive-based instruction, problem-based learning, technology-enhanced learning, assessment-based approaches, flipped classroom models, and cognitive tools. Among these, metacognitive-based instruction emerged as the most dominant approach, primarily supporting the monitoring and evaluation phases of SRL. However, the analysis indicates that the planning phase of SRL remains underrepresented across the reviewed studies. These results highlight an imbalance in the implementation of SRL in chemistry education, where reflective processes are emphasized more than proactive learning planning. Therefore, more integrated instructional designs are needed to explicitly support all phases of SRL, including planning, monitoring, and evaluation. This study contributes to the field by providing a thematic synthesis of instructional approaches and identifying key research gaps for future research.

Keywords: Self-regulated learning, Chemistry education, Instructional strategies

Abstrak: Pendekatan Pembelajaran untuk Mengembangkan Self-Regulated Learning dalam Pembelajaran Kimia: Sebuah Systematic Literature Review. *Penelitian ini bertujuan untuk mengidentifikasi dan menganalisis pendekatan pembelajaran yang digunakan untuk mengembangkan self-regulated learning (SRL) dalam pendidikan kimia melalui systematic literature review (SLR). Studi ini mengikuti pedoman PRISMA dengan mengumpulkan 100 artikel dari berbagai basis data akademik, termasuk Scopus, Web of Science, ERIC, dan Google Scholar. Setelah proses penghapusan duplikasi, diperoleh 98 artikel yang kemudian disaring berdasarkan judul dan abstrak, sehingga 60 artikel dinyatakan relevan. Selanjutnya, melalui tahap evaluasi teks lengkap berdasarkan kriteria inklusi dan eksklusi, diperoleh 40 artikel yang memenuhi syarat dan dianalisis lebih lanjut. Data dianalisis menggunakan pendekatan sintesis tematik untuk mengelompokkan jenis pendekatan pembelajaran dan komponen SRL yang dikembangkan. Hasil* *penelitian menunjukkan bahwa pendekatan pembelajaran dalam pendidikan kimia dapat dikategorikan ke dalam enam kelompok utama, yaitu pendekatan berbasis metakognisi, problem-based learning, pembelajaran berbasis teknologi, pendekatan berbasis asesmen, flipped classroom, dan penggunaan alat kognitif. Pendekatan berbasis metakognisi merupakan yang paling dominan dan berperan penting dalam mendukung proses monitoring dan evaluasi dalam SRL. Namun, sebagian besar pendekatan pembelajaran masih kurang memberikan perhatian pada fase perencanaan (planning) dalam SRL. Temuan ini menunjukkan adanya ketidakseimbangan dalam implementasi SRL dalam pembelajaran kimia, di mana aspek refleksi lebih banyak dikembangkan dibandingkan perencanaan pembelajaran. Oleh karena itu, diperlukan desain pembelajaran yang lebih terintegrasi yang secara eksplisit mendukung seluruh siklus SRL, termasuk perencanaan, monitoring, dan evaluasi. Penelitian ini memberikan kontribusi berupa sintesis tematik pendekatan pembelajaran serta mengidentifikasi celah penelitian yang dapat menjadi arah pengembangan studi selanjutnya.*

Kata kunci: *Self-regulated learning, pembelajaran kimia, strategi pembelajaran*

INTRODUCTION

Self-regulated learning (SRL) has become a central focus in contemporary educational research due to its significant role in enhancing students’ academic performance, autonomy, and lifelong learning skills (Panadero, 2017a; Xu, Zhao, Liew, Zhou, & Kogut, 2023a). SRL refers to learners’ ability to actively plan, monitor, and evaluate their own learning processes, enabling them to adapt strategies according to learning demands (Panadero, 2017a). In science education, particularly in chemistry, SRL is considered essential because of the subject’s abstract concepts, multiple representations, and high cognitive demands, which require students to engage in deep and strategic learning processes (Baptista, Martins, Conceição, & Reis, 2019; Rakhunwana, Kritzinger, & Pilcher, 2025; Roche Allred & Bretz, 2019).

In the context of chemistry education, students often face difficulties in understanding complex topics such as stoichiometry, chemical equilibrium, and reaction mechanisms (Gulacar, Overton, Bowman, & Fynewever, 2013; Hamnell-Pamment, 2024). These challenges are not only conceptual but also related to how students regulate their learning. Previous studies have shown that students with well-developed SRL skills are more capable of managing these challenges, as they can plan their learning, monitor their understanding, and evaluate their progress effectively (Kadioglu-Akbulut & Uzuntiryaki-Kondakci, 2021a). Therefore, fostering SRL has become an important objective in chemistry teaching and learning.

To support the development of SRL, various instructional approaches have been implemented, including metacognitive-based instruction, problem-based learning, flipped classroom models, technology-enhanced learning, and assessment-based strategies (Dochy, Segers, Van den Bossche, & Gijbels, 2003; Panadero, 2017b). For instance, metacognitive instruction has been widely used to enhance students’ awareness of their thinking processes, while problem-based learning encourages active engagement and strategic problem solving. Similarly, digital learning environments and feedback-based systems have been shown to support monitoring and reflection processes (Faza & Lestari, 2025). Despite these efforts, the effectiveness of these approaches varies depending on how they are designed and implemented.

Although numerous studies have explored instructional approaches related to SRL, the existing literature tends to focus on specific strategies or isolated interventions.

There is still a lack of comprehensive synthesis that systematically examines how different instructional approaches contribute to various components of SRL in chemistry education. In particular, limited attention has been given to the balance among SRL phases, namely planning, monitoring, and evaluation, within instructional practices. This gap highlights the need for a systematic review that not only categorizes instructional approaches but also critically analyzes their contributions to the development of SRL. Compared with previous studies that mostly examine SRL in broader science or general educational contexts, this review focuses specifically on chemistry education and maps how instructional approaches support each phase of SRL. In doing so, the present study extends earlier work by not only identifying instructional strategies, but also explicitly analyzing the imbalance in attention across planning, monitoring, and evaluation phases within chemistry learning contexts.

Therefore, this study aims to conduct a systematic literature review to identify and analyze instructional approaches used to foster self-regulated learning in chemistry education. Specifically, this study seeks to (1) classify the types of instructional approaches implemented in chemistry learning, (2) examine the SRL components addressed by these approaches, and (3) identify gaps and future research directions in the development of SRL within chemistry education. By providing a comprehensive synthesis of existing studies, this research is expected to contribute to the design of more effective and integrated instructional strategies that support students' self-regulated learning.

METHOD

This study employed a systematic literature review (SLR) to identify, analyze, and synthesize instructional approaches that foster self-regulated learning (SRL) in chemistry education. The review was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework to ensure a transparent, systematic, and reproducible process. A comprehensive literature search was conducted across several academic databases, including Scopus, Web of Science, ERIC, and Google Scholar, to capture relevant peer-reviewed studies. The search strategy combined key terms related to self-regulated learning and chemistry education, such as "self-regulated learning," "metacognition," "chemistry education," and "instructional approach," using Boolean operators to refine the results. The search was limited to publications in English within the time range of 2000 to 2025 to include both foundational and recent developments in the field.

To ensure the relevance and quality of the selected studies, predefined inclusion and exclusion criteria were applied. Studies were included if they focused on chemistry education, addressed self-regulated learning or closely related constructs such as metacognition or self-directed learning, and involved an instructional approach, such as a teaching strategy, learning model, or pedagogical intervention. Both empirical studies and relevant review articles published in peer-reviewed journals or conference proceedings were considered. Studies were excluded if they were not related to chemistry education, focused solely on motivation or achievement without incorporating SRL components, lacked a clear instructional intervention, were duplicates, or contained insufficient bibliographic information.

The study selection process was conducted in several stages following the PRISMA procedure. Initially, a total of 80 articles were identified through database searches and reference tracking. These articles were then screened based on their titles and abstracts to assess their relevance to SRL and chemistry education. Subsequently, full-text screening was performed to evaluate the alignment of each study with the focus on instructional approaches that support SRL. Based on this process, the studies were categorized into core studies (high relevance), supporting studies (moderate relevance), and excluded studies (low relevance). Duplicate records were identified and removed during the screening phase to ensure the integrity of the dataset.

Data extraction was carried out using a structured approach to ensure consistency across all selected studies. Key information extracted from each article included the authors, year of publication, study context (e.g., general chemistry, organic chemistry, laboratory settings), instructional approach employed (e.g., metacognitive training, problem-based learning, flipped classroom), components of SRL addressed (e.g., planning, monitoring, and evaluation), key findings, and digital object identifier (DOI). This systematic extraction enabled a comprehensive comparison of instructional approaches across studies. The data were analyzed using a thematic synthesis approach. Initially, instructional approaches were coded based on their characteristics and pedagogical focus. These codes were then grouped into broader thematic categories, including metacognitive-based instruction, problem-based and inquiry-based learning, technology-enhanced learning, assessment-based approaches, flipped and active learning models, and the use of cognitive tools. Through this process, patterns and relationships across studies were identified to understand how different instructional approaches contribute to the development of SRL in chemistry education.

To enhance the reliability of the screening and coding process, an inter-rater agreement procedure was implemented. Two reviewers independently evaluated a subset of the articles during the title–abstract screening and full-text review stages. The level of agreement between the reviewers was calculated using Cohen's kappa coefficient, which indicated a substantial level of agreement ($\kappa > 0.75$). Any discrepancies in study selection or classification were discussed and resolved through consensus, ensuring the consistency and validity of the review process. Finally, although a formal risk-of-bias assessment tool was not employed, the quality of the included studies was considered based on the clarity of research design, relevance to SRL and chemistry education, and the presence of well-defined instructional interventions. Particular attention was given to studies published in reputable journals in chemistry education, as these are more likely to demonstrate methodological rigor and contribute meaningful insights to the field. PRISMA Flow Diagram for this research shown in Figure 1.

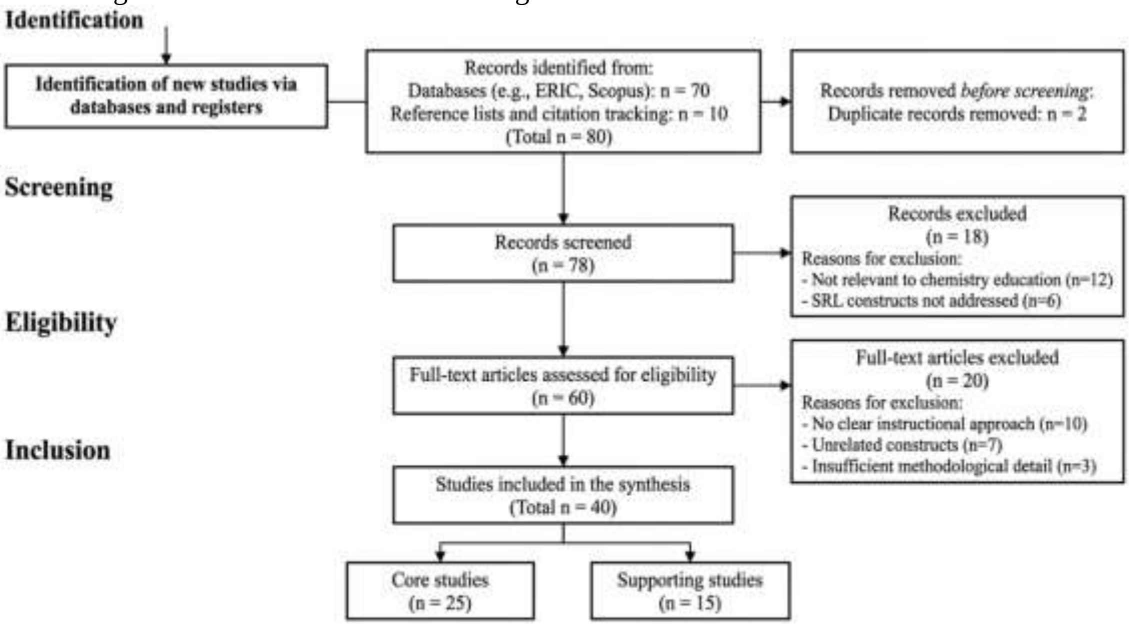

Figure 1. PRISMA Flow Diagram

RESULT AND DISCUSSION

The selected studies were systematically analyzed to identify patterns in instructional approaches that support the development of self-regulated learning (SRL) in chemistry education. Following the screening and eligibility process, a total of 40 studies were included in the final synthesis. These studies represent diverse educational contexts, including general chemistry, organic chemistry, secondary education, and higher education settings. The analysis focused on key elements such as the type of instructional approach, the specific SRL components addressed, and the broader pedagogical categories emerging from the literature.

To provide a structured overview of the included studies, a data extraction table was developed summarizing essential information from each article, including the authors, publication year, instructional approach, SRL components, and digital object identifiers (DOIs). The studies were further categorized into thematic groups such as metacognitive-based instruction, problem-based learning, technology-enhanced learning, assessment-based approaches, flipped classroom models, and cognitive tools. This categorization enables a clearer understanding of how different instructional strategies contribute to fostering SRL in chemistry education and serves as the basis for the subsequent thematic analysis.

Table 1. Summary of the Included Studies and Their Instructional Approaches for Fostering Self-Regulated Learning in Chemistry Education (n = 40)

No	Author (Year)	Context	Instructional Approach	SRL Component	Category
1	(Castillo-Cruz, González-Espada, Vedrine-Pauléus, & Casillas-Martínez, 2025)	Intro Chemistry	Flipped + Active Learning	Planning, Monitoring	Flipped
2	(Adduriyah Auliya & Utiya Azizah, 2025)	Chemistry Learning	SRL-Oriented Material	Planning	Digital
3	(R. Chen & Cromley, 2025)	Chemistry	Problem-Solving Strategy	Planning	PBL
4	(Ali Khalif, Omidian, Abdul-Hassan Owaid, & Saeidian, 2025)	Education	SRL Conceptual Model	Planning	Metacognitive
5	(Avelino & Bizerra, 2025)	Chemistry Education	SRL Perception Study	Monitoring	Metacognitive
6	(Hewitt, Fall, Puvanendran, Mwavita, & Mutambuki, 2025)	General Chemistry	Metacognitive Instruction	Monitoring, Evaluation	Metacognitive
7	(Ferguson & Bonner, 2024)	Organic Chemistry	Ungrading (Self-Assessment)	Evaluation, Reflection	Assessment
8	(Carpenter & Hodges, 2024)	General Chemistry	Spaced Practice Strategy	Monitoring	Metacognitive
9	(Richards-Babb, Gordon, Mersing, Perrone, & Ratcliff, 2025)	Chemistry	Metacognitive Reporting	Monitoring	Metacognitive
10	(Candrawinata, Erlina, & Ulfah, 2024)	Chemistry Education	Metacognition–SDL Approach	Monitoring	Metacognitive
11	(Yu et al., 2024)	Higher Education	Technology-Based SRL	Monitoring	Digital

No	Author (Year)	Context	Instructional Approach	SRL Component	Category
12	(Muisener, Ibarrola Recalde, & Baxter, n.d.)	General Chemistry	Reflective Practice	Evaluation	Assessment
13	(Blackford et al., 2023a)	Organic Chemistry	Metacognitive Regulation	Monitoring, Evaluation	Metacognitive
14	(Lawrie, Bailey, Blanchfield, & Schultz, 2017)	Chemistry Learning	Feedback-Based Learning	Monitoring	Digital
15	(Mendes & Mendes, 2023)	Higher Ed Chemistry	Self-Assessment Strategy	Evaluation	Assessment
16	(Vera-Monroy, Gamboa-Mora, & Mejía-Camacho, 2023)	General Chemistry	Rubric-Based Assessment	Evaluation	Assessment
17	(Wu, Sun, Yang, Li, & Sun, 2023)	Secondary Chemistry	SRL Implementation	Monitoring	Metacognitive
18	(Feldman-Maggor, 2023)	Chemistry Classroom	SRL Practice Implementation	Monitoring	Metacognitive
19	(SOUSA & BATINGA, 2023)	Chemistry Education	Problem-Solving Approach	Planning, Evaluation	PBL
20	(Jusniar, Syamsidah, & Munawwarah, 2023)	Chemistry Learning	Modified Problem-Based Learning	Planning	PBL
21	(Richards-Babb et al., 2025)	Chemistry	Formative Metacognitive Reporting	Monitoring	Metacognitive
22	(Muhab, Irwanto, Allanas & Yodela, 2022)	Chemistry	Online SRL Intervention	Monitoring	Digital
23	(K.-Z. Chen & Li, 2021a)	Online Chemistry	Learning Analytics Approach	Monitoring	Digital
24	(Li, Wang, Stone, & Turki, 2021)	Online Chemistry	Socio-Cognitive Instruction	Monitoring	Digital
25	(Muteti et al., 2021a)	General Chemistry	Explicit Metacognitive Teaching	Planning, Monitoring	Metacognitive
26	(Abarro & Asuncion, 2021)	Chemistry	Metacognitive Review	Monitoring	Metacognitive
27	(Higgins, Frankland, & Rathner, 2021)	Science Education	SRL Framework Study	Monitoring	Metacognitive
28	(Syahmani, 2019)	Chemistry Learning	SRL Model with Mind Mapping	Monitoring	Cognitive Tools
29	(Ijirana & Supriadi, 2018)	Chemistry Education	Metacognitive-Based Learning	Planning	Metacognitive
30	(Sinaga, 2018)	Basic Chemistry	Flipped Classroom Model	Planning	Flipped
31	(López-Crespo, Blanco-Gandía, Valdivia-Salas, Fidalgo, & Sánchez-Pérez, 2022)	Organic Chemistry	SRL Study Strategies	Planning	Metacognitive
32	Saribas & Bayram (2010)	Laboratory Science	Metacognitive Lab Instruction	Monitoring	Metacognitive
33	Opara (2010)	Stoichiometry	Mind Mapping Strategy	Planning	Cognitive Tools
34	Espinosa et al. (2024)	Chemistry Education	Confidence Judgment Strategy	Evaluation	Assessment
35		Chemistry	Competency-Based Assessment	Evaluation	Assessment
36	Clark et al. (2024)	STEM	Flipped + Metacognitive Support	Monitoring	Flipped

No	Author (Year)	Context	Instructional Approach	SRL Component	Category
37	(K.-Z. Chen & Li, 2021b)	Chemistry	SRL Learning Analytics	Monitoring	Digital
38	(Roberts, 2021)	Online Learning	Learning Plan Strategy	Monitoring	Metacognitive
39	(Lawrie, 2023)	Chemistry	Digital Feedback Approach	Monitoring	Digital
40	(Blackford et al., 2023b)	Organic Chemistry	Metacognitive Strategy Use	Monitoring	Metacognitive

As shown in Table 1, metacognitive-based instructional approaches appear as the most dominant strategy across the reviewed studies, followed by technology-enhanced learning and assessment-based approaches. Most studies emphasize the development of monitoring and evaluation processes, which are central components of SRL, while fewer studies explicitly address the planning phase. This pattern suggests that instructional practices in chemistry education tend to focus more on supporting students' reflective and evaluative processes rather than their initial learning planning and goal-setting stages.

These findings highlight an important trend in the literature, indicating that while various instructional approaches have been implemented to promote SRL, their effectiveness often depends on the extent to which they explicitly incorporate metacognitive and reflective elements. In particular, approaches that integrate structured feedback, self-assessment, and guided reflection appear to provide stronger support for SRL development compared to approaches that rely solely on content delivery or activity design. Building on these observations, the following section presents a thematic analysis of instructional approaches identified in the reviewed studies. Each category is discussed in detail to examine how specific pedagogical strategies contribute to different dimensions of self-regulated learning in chemistry education.

Overview of Instructional Approaches in Chemistry SRL Studies

A total of 40 studies were included in the final synthesis, representing a diverse range of instructional approaches used to foster self-regulated learning (SRL) in chemistry education. The extracted data reveal that instructional approaches can be broadly categorized into six main groups: metacognitive-based instruction, problem-based learning (PBL), technology-enhanced learning, assessment-based approaches, flipped classroom models, and cognitive tools. Across the reviewed studies, metacognitive-based instruction emerged as the most dominant category, followed by technology-enhanced learning and assessment-based approaches. In contrast, approaches such as flipped classroom models and cognitive tools appeared less frequently but demonstrated targeted contributions to specific SRL components.

Table 2. Distribution of Instructional Approaches Across Studies

Category	Number of Studies	Percentage
Metacognitive-based instruction	15	37.5%
Digital / Technology-enhanced	9	22.5%
Assessment-based approaches	6	15%
Problem-based learning (PBL)	4	10%
Flipped classroom	3	7.5%
Cognitive tools	3	7.5%
Total	**40**	**100%**

The dominance of metacognitive-based instruction across the reviewed studies suggests that the promotion of self-regulated learning in chemistry education is most frequently approached through efforts to strengthen students' awareness of their own thinking and learning processes. This pattern is understandable, given that chemistry is a discipline characterized by abstract concepts, symbolic representations, and complex problem-solving demands. In such contexts, students are not only expected to understand content, but also to continuously monitor their comprehension, identify misconceptions, and evaluate the effectiveness of the strategies they use. As a result, metacognitive instruction appears to provide a strong pedagogical foundation for supporting SRL, particularly because it directly addresses the internal regulatory processes that underlie successful learning.

The relatively high proportion of technology-enhanced learning and assessment-based approaches further indicates that current instructional practices tend to support SRL through feedback, reflection, and performance tracking. Digital environments often provide immediate feedback and flexible access to learning resources, which can help students monitor their progress more effectively. Similarly, assessment-based approaches such as self-assessment, rubric-guided evaluation, and reflective tasks encourage learners to examine their own performance and make judgments about their understanding. However, the lower representation of problem-based learning, flipped classroom models, and cognitive tools suggests that approaches which more explicitly support strategic preparation and learner autonomy are still less frequently implemented in the literature. This may indicate that many studies prioritize supporting regulation during and after learning rather than before learning begins.

Taken together, the distribution presented in Table 2 reveals that instructional approaches in chemistry SRL research are not evenly balanced, but instead show a strong concentration on approaches that foster metacognitive engagement. This finding is important because it indicates that SRL in chemistry education is commonly interpreted through the lens of monitoring and reflection rather than as a fully integrated cycle involving planning, monitoring, and evaluation. Consequently, although the reviewed studies demonstrate substantial progress in supporting SRL, they also point to a need for more comprehensive instructional designs that combine metacognitive support with approaches that explicitly strengthen students' capacity to plan, organize, and strategically manage their learning from the outset.

SRL Components Addressed by Instructional Approaches

Further analysis of the extracted data indicates that instructional approaches do not equally target all phases of SRL. Instead, there is a clear imbalance in how SRL components are addressed.

Table 3. Frequency of SRL Components Across Studies

SRL Component	Frequency	Dominance
Monitoring	28	High
Evaluation / Reflection	22	High
Planning	14	Moderate

The distribution of SRL components presented in Table 3 indicates that the reviewed instructional approaches place the strongest emphasis on monitoring and evaluation/reflection, while planning receives comparatively less attention. This pattern suggests that most interventions in chemistry education are designed to help students track their understanding, reflect on their performance, and make sense of errors or progress during and after learning. Such an emphasis is pedagogically meaningful in chemistry, where students often encounter abstract concepts, multistep problem solving, and representational challenges that require continuous checking of understanding. As a result, monitoring and reflection become highly visible and measurable components of SRL in instructional practice.

At the same time, the lower frequency of planning reveals an important limitation in the existing literature. Planning is a critical phase of SRL because it involves goal setting, strategic preparation, time management, and the selection of appropriate learning strategies before students begin a task. However, compared with monitoring and evaluation, fewer studies explicitly incorporate instructional designs that support these proactive aspects of self-regulation. This finding implies that SRL in chemistry education is often facilitated in a reactive manner, where students are encouraged to respond to learning difficulties once they arise, rather than being systematically prepared to anticipate and manage those difficulties from the outset.

This imbalance has important implications for both instructional design and future research. From an instructional perspective, the findings suggest that chemistry learning environments would benefit from more deliberate integration of activities that foster planning, such as goal-setting prompts, pre-task strategy selection, and structured preparation before problem solving or laboratory work. From a research perspective, the dominance of monitoring and evaluation also points to a gap in how SRL has been conceptualized and operationalized in chemistry education. Rather than addressing SRL as a complete cycle, many studies appear to focus only on selected phases. Therefore, future studies should aim to design and examine more comprehensive instructional approaches that support the full SRL process, including planning, monitoring, and evaluation in a more balanced and connected manner.

Thematic Analysis of Instructional Approaches

To complement the tabular findings, a conceptual visualization was developed to illustrate the relationship between the instructional approaches identified in the reviewed studies and the specific components of self-regulated learning (SRL) they most frequently support. As shown in Figure 2, each instructional category contributes differently to the development of SRL, with some approaches emphasizing planning, others strengthening monitoring, and several focusing on evaluation and reflection. This figure helps synthesize the thematic patterns emerging from the reviewed studies and provides a clearer representation of how instructional design in chemistry education tends to support particular phases of the SRL process rather than the full cycle in an equally balanced manner.

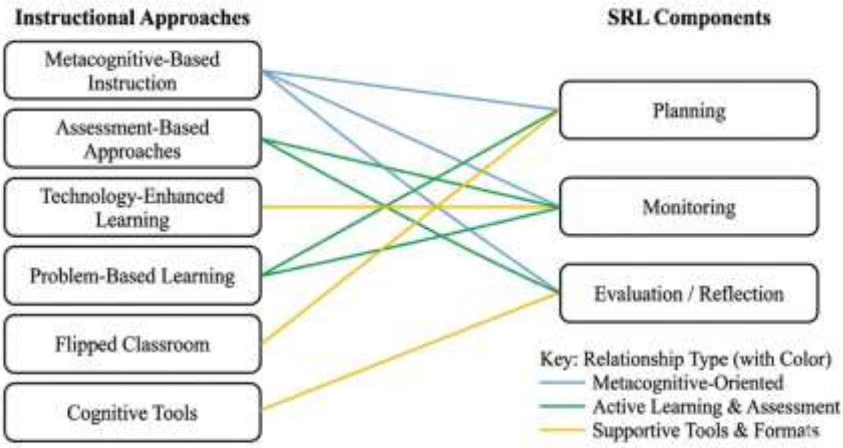

Figure 2. Conceptual relationship between instructional approaches and SRL Components

Figure 2 provides a clearer conceptual synthesis of how the instructional approaches identified in the reviewed studies are connected to specific components of self-regulated learning. The figure shows that metacognitive-based instruction has the broadest relationship with SRL because it is linked not only to monitoring, but also to planning and evaluation/reflection. This pattern reinforces the finding that metacognitive approaches serve as the most comprehensive pedagogical route for fostering SRL in chemistry education. Since chemistry learning often requires students to interpret abstract concepts, coordinate multiple representations, and solve complex problems, instructional support that helps learners become aware of their cognitive processes is particularly important. In this sense, metacognitive-based instruction appears to function as a central bridge between instructional design and the internal regulatory processes required for successful chemistry learning.

The figure also highlights that other instructional approaches contribute to SRL in more specific and targeted ways. Assessment-based approaches are strongly aligned with evaluation and reflection, suggesting that they are especially effective in encouraging students to judge their own understanding and learning progress. Technology-enhanced learning is primarily associated with monitoring, which reflects the role of digital environments in providing feedback, progress tracking, and continuous learning support. Meanwhile, problem-based learning connects with both planning and monitoring, indicating that it can support students in organizing strategies before engaging with a task while also helping them track their reasoning during problem solving. Flipped classroom models and cognitive tools appear to be more closely related to planning, as both approaches require students to prepare, organize information, and structure their learning before or during engagement with chemistry tasks.

Taken together, Figure 2 demonstrates that no single instructional approach supports all SRL components in a perfectly balanced manner, although metacognitive-based instruction comes closest to doing so. This finding is important because it suggests that fostering SRL in chemistry education may require not merely selecting one instructional model, but designing integrated learning environments that combine multiple approaches. For example, metacognitive prompts may be combined with digital feedback, reflective assessment, and structured problem-solving tasks to support the full SRL cycle more effectively. Therefore, the figure not only summarizes the thematic patterns identified in the reviewed studies, but also points to an important pedagogical implication: SRL development in chemistry is likely to be strengthened when instructional approaches are used complementarily rather than in isolation.

Synthesis and Research Gap

Taken together, the findings of this review show that instructional approaches for fostering self-regulated learning (SRL) in chemistry education are largely concentrated on helping students regulate their learning during and after the learning process, rather than before it begins. This pattern is consistent with recent studies showing that chemistry instruction most often emphasizes metacognitive awareness, self-monitoring, and reflective adjustment rather than explicit preparation before learning tasks begin. In chemistry classrooms, metacognitive instruction has been shown to increase students' awareness and adoption of effective study strategies, especially those related to monitoring and regulating learning processes (Kadioglu-Akbulut & Uzuntiryaki-Kondakci, 2021b; Muteti et al., 2021b). Likewise, research in organic and general chemistry indicates that metacognitive regulation, feedback, and reflective activities are particularly effective for strengthening students' monitoring and evaluation of their own learning, while planning-oriented supports remain less visible in instructional practice (Blackford et al., 2023c; Kyne, Lee, & Reyes, 2023). In contrast, approaches that explicitly support planning, such as goal setting, strategic preparation, and pre-task regulation, were less frequently represented, suggesting that SRL in chemistry education is still more often implemented as a reactive process than as a proactive and cyclical one.

This synthesis also suggests that the literature tends to conceptualize SRL through partial instructional support rather than through integrated designs that address the full SRL cycle. Although problem-based learning, flipped classroom models, and cognitive tools show potential for strengthening planning and strategic preparation, these approaches appear less dominant and are often implemented without explicit integration with metacognitive reflection or assessment mechanisms. Recent chemistry education studies support this interpretation. For example, structured metacognitive scaffolding in chemistry problem solving has been found to help students engage more systematically with planning and evaluation, yet students still require repeated opportunities, feedback, and reflection before such strategies become internalized (Vo, Sarkar, White, & Yuriev, 2024, 2025). Similarly, technology-enhanced environments can support SRL through analytics, feedback, and progress tracking, but their impact depends strongly on pedagogical design rather than the mere presence of technology (K.-Z. Chen & Li, 2021a; Kyne, Lee, & Reyes, 2023). Broader recent reviews also conclude that digital tools are most effective when they are embedded in instructional practices such as scaffolding, coaching, and feedback that deliberately promote reflection and strategy use. Overall, the reviewed evidence suggests that different instructional approaches contribute to SRL in complementary ways, yet they are still rarely combined in a manner that systematically supports planning, monitoring, and evaluation as interconnected phases.

Based on these findings, several research gaps can be identified. First, there is a clear lack of studies that explicitly emphasize the planning phase of SRL in chemistry education; this concern is in line with recent evidence showing that the preparatory phase remains underexplored compared with monitoring and reflection phases in SRL research. Future research should therefore pay greater attention to instructional designs that support goal setting, time management, strategy selection, and preparation before students engage in chemistry learning tasks. Second, there is still limited evidence on the effectiveness of integrated instructional models that combine metacognitive prompts, digital feedback, self-assessment, and problem-solving activities within a single chemistry learning design, even though recent studies suggest such combinations are promising for strengthening structured and reflective problem solving (Ferguson & Bonner, 2024a; Vo, Sarkar, White, & Yuriev, 2024, 2025). Third, most existing studies focus on relatively short-term interventions, whereas recent work points to the importance of examining how SRL develops over time and across learning episodes before stronger conclusions can be drawn about sustained instructional impact. Finally, further research is needed across more diverse chemistry topics, educational levels, and learner groups, because recent chemistry studies have also highlighted differences in SRL development across demographic and instructional contexts.

These gaps indicate that future scholarship should move beyond identifying isolated instructional strategies and instead focus on designing more coherent and comprehensive learning environments that foster the full cycle of self-regulated learning. In this regard, the present review not only synthesizes the dominant instructional approaches found in the literature, but also highlights the need for a more balanced and integrative direction in both research and instructional practice.

CONCLUSION

This systematic literature review examined instructional approaches for fostering self-regulated learning (SRL) in chemistry education by synthesizing evidence from 40 selected studies. The findings indicate that a wide range of instructional strategies has been employed to support SRL, with metacognitive-based instruction emerging as the most dominant approach, followed by technology-enhanced learning and assessment-based strategies. These approaches primarily support the monitoring and evaluation phases of SRL, highlighting the central role of reflective and metacognitive processes in chemistry learning. However, a key finding of this review is the limited emphasis on the planning phase of SRL, suggesting that current instructional practices tend to focus more on helping students reflect on their learning rather than preparing them to plan and regulate their learning proactively. This imbalance points to a partial implementation of SRL frameworks in chemistry education and underscores the need for more comprehensive instructional designs that address all phases of the SRL cycle.

This study contributes to the field by providing a thematic synthesis of instructional approaches and identifying critical gaps in the literature. The findings suggest that effective support for SRL in chemistry education requires the integration of multiple instructional elements, including metacognitive scaffolding, structured feedback, self-assessment, and opportunities for active engagement. Future research should focus on developing and testing integrated instructional models that explicitly support planning, monitoring, and evaluation processes, as well as exploring the long-term development of SRL skills in diverse chemistry learning contexts. Ultimately, fostering self-regulated learning in chemistry education requires a shift from fragmented instructional practices toward more coherent and explicitly designed learning environments that support the full cycle of self-regulation. Practically, this review suggests that chemistry teachers should implement instructional designs that explicitly support students in setting goals, planning strategies, monitoring understanding, and reflecting on learning outcomes. This can be achieved through the use of goal-setting activities, learning journals, self-assessment tasks, and structured feedback integrated into chemistry instruction. Future research should focus on testing integrated instructional models that address all SRL phases and on conducting longitudinal studies across diverse chemistry learning contexts to examine the sustained development of students' self-regulated learning skills.

REFERENCES

Abarro, R. Q., & Asuncion, J. E. (2021). Metacognition In Chemistry Education. *Theoretical & Applied Science*, *95*(03), 1–22. https://doi.org/10.15863/TAS.2021.03.95.1

Adduriyah Auliya, S., & Utiya Azizah. (2025). Development of an Acid-Base Supplement Book Oriented to Self Regulated Learning (SRL) to Improve Students Metacognitive Skills. *International Journal of Educational Research*, *2*(2), 141–148. https://doi.org/10.62951/ijer.v2i2.346

Ali Khalif, S., Omidian, F., Abdul-Hassan Owaid, F., & Saeidian, N. (2025). Providing a Conceptual Model for Developing Self-Directed Learning in Students. *Iranian Journal of Educational Sociology*, *8*(2), 1–10. https://doi.org/10.61838/kman.ijes.8.2.15

Avelino, A. C. da S., & Bizerra, A. M. C. (2025). A autorregulação da aprendizagem no ensino de Química: percepções e práticas de licenciandos no contexto da pandemia da Covid-19. *Temas & Matizes*, *18*(34), 232–260. https://doi.org/10.48075/rtm.v18i34.30854

Baptista, M., Martins, I., Conceição, T., & Reis, P. (2019). Multiple representations in the development of students' cognitive structures about the saponification reaction. *Chemistry Education Research and Practice*, *20*(4), 760–771. https://doi.org/10.1039/C9RP00018F

Blackford, K. A., Greenbaum, J. C., Redkar, N. S., Gaillard, N. T., Helix, M. R., & Baranger, A. M. (2023a). Metacognitive regulation in organic chemistry students: how and why students use metacognitive strategies when predicting reactivity. *Chemistry Education Research and Practice*, *24*(3), 828–851. https://doi.org/10.1039/D2RP00208F

Blackford, K. A., Greenbaum, J. C., Redkar, N. S., Gaillard, N. T., Helix, M. R., & Baranger, A. M. (2023b). Metacognitive regulation in organic chemistry students: how and why students use metacognitive strategies when predicting reactivity. *Chemistry Education Research and Practice*, *24*(3), 828–851. https://doi.org/10.1039/D2RP00208F

Blackford, K. A., Greenbaum, J. C., Redkar, N. S., Gaillard, N. T., Helix, M. R., & Baranger, A. M. (2023c). Metacognitive regulation in organic chemistry students: how and why students use metacognitive strategies when predicting reactivity. *Chemistry Education Research and Practice*, *24*(3), 828–851. https://doi.org/10.1039/D2RP00208F

Candrawinata, N., Erlina, E., & Ulfah, M. (2024). The Relationship Between Metacognitive Ability and Self-directed Learning of Chemistry Education Students as Prospective Teacher. *Hydrogen: Jurnal Kependidikan Kimia*, *12*(4), 893. https://doi.org/10.33394/hjkk.v12i4.12349

Carpenter, T. S., & Hodges, L. C. (2024). Student Responses to Spaced Practice in Two Large Gateway Chemistry Courses. *Journal of Chemical Education*, *101*(2), 429–437. https://doi.org/10.1021/acs.jchemed.3c00773

Castillo-Cruz, B., González-Espada, W., Vedrine-Pauléus, J., & Casillas-Martínez, L. (2025). Incorporating Active Learning and Inclusive Practices in a Flipped

Environment: Findings from Introductory Chemistry at a Hispanic Serving Institution. *Journal of Chemical Education*, *102*(8), 3346–3354. https://doi.org/10.1021/acs.jchemed.5c00123

Chen, K.-Z., & Li, S.-C. (2021a). Sequential, typological, and academic dynamics of self-regulated learners: Learning analytics of an undergraduate chemistry online course. *Computers and Education: Artificial Intelligence*, *2*, 100024. https://doi.org/10.1016/j.caeai.2021.100024

Chen, K.-Z., & Li, S.-C. (2021b). Sequential, typological, and academic dynamics of self-regulated learners: Learning analytics of an undergraduate chemistry online course. *Computers and Education: Artificial Intelligence*, *2*, 100024. https://doi.org/10.1016/j.caeai.2021.100024

Chen, R., & Cromley, J. (2025). Does academic motivation relate to students' use of problem-solving strategies in chemistry: a study of first-year college students / *¿Existe una relación entre la motivación académica y el uso de estrategias de resolución de problemas por parte de los estudiantes de Química? Un estudio con estudiantes universitarios de primer curso*. *Journal for the Study of Education and Development: Infancia y Aprendizaje*, *48*(4), 794–829. https://doi.org/10.1177/02103702251347883

Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: a meta-analysis. *Learning and Instruction*, *13*(5), 533–568. https://doi.org/10.1016/S0959-4752(02)00025-7

Faza, A., & Lestari, I. A. (2025). Self-Regulated Learning in the Digital Age: A Systematic Review of Strategies, Technologies, Benefits, and Challenges. *The International Review of Research in Open and Distributed Learning*, *26*(2), 23–58. https://doi.org/10.19173/irrodl.v26i2.8119

Feldman-Maggor, Y. (2023). Identifying self-regulated learning in chemistry classes – a good practice report. *Chemistry Teacher International*, *5*(2), 203–211. https://doi.org/10.1515/cti-2022-0036

Ferguson, J. H., & Bonner, L. A. (2024). Ungrading in organic chemistry: students assessing themselves and reflecting on their learning. *Frontiers in Education*, *9*. https://doi.org/10.3389/feduc.2024.1394042

Gulacar, O., Overton, T. L., Bowman, C. R., & Fynewever, H. (2013). A novel code system for revealing sources of students' difficulties with stoichiometry. *Chem. Educ. Res. Pract.*, *14*(4), 507–515. https://doi.org/10.1039/C3RP00029J

Hamnell-Pamment, Y. (2024). Making sense of chemical equilibrium: productive teacher–student dialogues as a balancing act between sensemaking and managing tension. *Chemistry Education Research and Practice*, *25*(1), 171–192. https://doi.org/10.1039/D3RP00249G

Hewitt, A., Fall, R., Puvanendran, S., Mwavita, M., & Mutambuki, J. M. (2025). Comparison of the Effects of Metacognition Instruction, Voices of Role Models, and the Synergy of the Interventions on Students' Achievement Scores and Perceived Belonging in a General Chemistry Course. *Journal of Chemical Education*, *102*(1), 183–193. https://doi.org/10.1021/acs.jchemed.4c00851

Higgins, N., Frankland, S., & Rathner, J. (2021). Self-Regulated Learning in Undergraduate Science. *International Journal of Innovation in Science and Mathematics Education*, *29*(1). https://doi.org/10.30722/IJISME.29.01.005

Jusniar, J., Syamsidah, S., & Munawwarah, M. (2023). Stimulating Metacognitive and Problem Solving-Skills Students' on Chemical Equilibrium through Modified

Problem-Based Learning (M-PBL) Strategy. *Jurnal Penelitian Pendidikan IPA*, *9*(2), 471–477. https://doi.org/10.29303/jppipa.v9i2.1753

Kadioglu-Akbulut, C., & Uzuntiryaki-Kondakci, E. (2021a). Implementation of self-regulatory instruction to promote students' achievement and learning strategies in the high school chemistry classroom. *Chemistry Education Research and Practice*, *22*(1), 12–29. https://doi.org/10.1039/C9RP00297A

Kadioglu-Akbulut, C., & Uzuntiryaki-Kondakci, E. (2021b). Implementation of self-regulatory instruction to promote students' achievement and learning strategies in the high school chemistry classroom. *Chemistry Education Research and Practice*, *22*(1), 12–29. https://doi.org/10.1039/C9RP00297A

Kyne, S. H., Lee, M. M. H., & Reyes, C. T. (2023). Enhancing academic performance and student success through learning analytics-based personalised feedback emails in first-year chemistry. *Chemistry Education Research and Practice*, *24*(3), 971–983. https://doi.org/10.1039/D3RP00032J

Lawrie, G. A. (2023). Embedding Feedback in Digital Learning Environments to Promote Learners' Thinking About Their Thinking in Chemistry. In *Digital Learning and Teaching in Chemistry* (pp. 352–368). The Royal Society of Chemistry. https://doi.org/10.1039/9781839167942-00352

Lawrie, G. A., Bailey, C., Blanchfield, J., & Schultz, M. (2017). *Insights into how students' 'selves' impact on their self-regulation and self-direction in online learning*. 77. Retrieved from https://openjournals.library.sydney.edu.au/index.php/IISME/article/download/10808/11349

Li, M., Wang, Y., Stone, H. N., & Turki, N. (2021). Teaching Introductory Chemistry Online: The Application of Socio-Cognitive Theories to Improve Students' Learning Outcomes. *Education Sciences*, *11*(3), 95. https://doi.org/10.3390/educsci11030095

López-Crespo, G., Blanco-Gandía, M. C., Valdivia-Salas, S., Fidalgo, C., & Sánchez-Pérez, N. (2022). The educational e-portfolio: preliminary evidence of its relationship with student's self-efficacy and engagement. *Education and Information Technologies*, *27*(4), 5233–5248. https://doi.org/10.1007/s10639-021-10827-2

Mendes, R. M., & Mendes, O. M. (2023). Eu me avalio e traço metas: a autoavaliação discente nas aulas de Química no ensino superior. *Contribuciones A Las Ciencias Sociales*, *16*(10), 19115–19132. https://doi.org/10.55905/revconv.16n.10-024

Muhab, S., Irwanto, I., Allanas, E., & Yodela, E. (2022). Improving Students' Self-Regulation Using Online Self- Regulated Learning In Chemistry. *Journal Of Sustainability Science And Management*, *17*(10), 1–12. https://doi.org/10.46754/jssm.2022.10.001

Muisener, P., Ibarrola Recalde, G., & Baxter, G. (n.d.). Self Reflection of Engineering Majors in General Chemistry II. *2021 ASEE Virtual Annual Conference Content Access Proceedings*. ASEE Conferences. https://doi.org/10.18260/1-2--37704

Muteti, C. Z., Zarraga, C., Jacob, B. I., Mwarumba, T. M., Nkhata, D. B., Mwavita, M., … Mutambuki, J. M. (2021a). I realized what I was doing was not working: the influence of explicit teaching of metacognition on students' study strategies in a general chemistry I course. *Chemistry Education Research and Practice*, *22*(1), 122–135. https://doi.org/10.1039/D0RP00217H

Muteti, C. Z., Zarraga, C., Jacob, B. I., Mwarumba, T. M., Nkhata, D. B., Mwavita, M., … Mutambuki, J. M. (2021b). I realized what I was doing was not working: the influence of explicit teaching of metacognition on students' study strategies in a general chemistry I course. *Chemistry Education Research and Practice*, *22*(1), 122–135. https://doi.org/10.1039/D0RP00217H

Panadero, E. (2017a). A Review of Self-regulated Learning: Six Models and Four Directions for Research. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00422

Panadero, E. (2017b). A Review of Self-regulated Learning: Six Models and Four Directions for Research. *Frontiers in Psychology*, *8*. https://doi.org/10.3389/fpsyg.2017.00422

Rakhunwana, L., Kritzinger, A., & Pilcher, L. A. (2025). Self-regulated learning strategies for success in an online first-year chemistry course. *Chemistry Education Research and Practice*, *26*(1), 300–314. https://doi.org/10.1039/D4RP00159A

Richards-Babb, M., Gordon, C. E., Mersing, D., Perrone, T., & Ratcliff, B. B. (2025). Promotion of Student Success and Positive Chemistry Course Perception through Frequent Metacognitive Reporting. *Journal of Chemical Education*, *102*(1), 102–111. https://doi.org/10.1021/acs.jchemed.4c00578

Roberts, J. S. (2021). Integrating Metacognitive Regulation into the Online Classroom Using Student-Developed Learning Plans. *Journal of Microbiology & Biology Education*, *22*(1). https://doi.org/10.1128/jmbe.v22i1.2409

Roche Allred, Z. D., & Bretz, S. L. (2019). University chemistry students' interpretations of multiple representations of the helium atom. *Chemistry Education Research and Practice, 20*(2), 358–368. https://doi.org/10.1039/C8RP00296G

Sinaga, K. (2018). Pengaruh Penerapan Flipped Classroom pada Mata Kuliah Kimia Dasar untuk Meningkatkan Self Regulated Learning. *EduChemia*, *3*(1), 106–118. https://doi.org/10.30870/EDUCHEMIA.V3I1.2626

Sinaga, K. (n.d.). *Penerapan flipped classroom pada mata kuliah kimia dasar untuk meningkatkan self-regulated learning belajar mahasiswa*. https://doi.org/10.15294/jipk.v11i2.10609

Sousa, Y. K. De, & Batinga, V. T. S. (2023). A Resolução De Problemas No Ensino De Química: Possibilidade Para Promoção Da Autorregulação De Aprendizagem. *International Journal Education And Teaching (PDVL) ISSN 2595-2498*, *6*(2), 36–51. https://doi.org/10.31692/ijetpdvl.v6i2.280

Syahmani, S. (2019). Self-Regulated Learning Model With Mind Map To Improve Students Cognition And Metacognition Skills In Solving Chemical Problems. *JPPS (Jurnal Penelitian Pendidikan Sains)*, *8*(2), 1690. https://doi.org/10.26740/jpps.v8n2.p1690-1698

Vera-Monroy, S. P., Gamboa-Mora, M. C., & Mejía-Camacho, A. (2023). Evaluación Por Competencias En Química General: Incidencia De Las Rúbricas En El Proceso De Metacognición. *Revista Prociências*, *6*(1), 84–99. https://doi.org/10.15210/prociencias.v6i1.5616

Wu, M., Sun, D., Yang, Y., Li, M., & Sun, J. (2023). Investigating students' performance at self-regulated learning and its effects on learning outcomes in chemistry class at the senior secondary school. *International Journal of Science Education*, *45*(16), 1395–1418. https://doi.org/10.1080/09500693.2023.2209693

Xu, Z., Zhao, Y., Liew, J., Zhou, X., & Kogut, A. (2023a). Synthesizing research evidence on self-regulated learning and academic achievement in online and blended learning environments: A scoping review. *Educational Research Review, 39*, 100510. https://doi.org/10.1016/j.edurev.2023.100510

Xu, Z., Zhao, Y., Liew, J., Zhou, X., & Kogut, A. (2023b). Synthesizing research evidence on self-regulated learning and academic achievement in online and blended learning environments: A scoping review. *Educational Research Review*, *39*, 100510. https://doi.org/10.1016/j.edurev.2023.100510

Yu, R., Yang, H., Lin, X., Yao, C., Burkander, P., Thomas, K., & Mislevy, J. (2024). Technology-Based Instructional Strategies Show Promise in Improving Self-Regulated Learning Skills at Broad-Access Postsecondary Institutions. *Proceedings of the Eleventh ACM Conference on Learning @ Scale*, 408–411. New York, NY, USA: ACM. https://doi.org/10.1145/3657604.3664675