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EDITED BY
Antonio P. Gutierrez de Blume,
Georgia Southern University, United States

REVIEWED BY
Peng He,
Michigan State University, United States
Jordi Colomer,
University of Girona, Spain

*CORRESPONDENCE
Jayme Del Mario
j.k.simlin@tcu.edu

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A literature review: analyzing barriers hindering the implementation of self-regulated learning in science classrooms

Jayme Del Mario[1]* and Hong Tran[2]

[1]College of Education, Andrews Institute for Research in Mathematics and Science Education, Texas Christian University, Ft. Worth, TX, United States, [2]School of Engineering Education, Purdue University, West Lafayette, IN, United States

Self-regulated learning is a goal-directed process in which learners are metacognitively, motivationally, and behaviorally active participants in their learning process. Although studies have shown self-regulated learning is critical for success in academic learning and beyond; many students do not use self-regulated learning strategies to drive their science learning. To better understand the circumstances surrounding this unfortunate situation, this literature review reports on 15 studies related to barriers that hinder science teachers from enacting self-regulated learning. In this review, we discuss the role of self-regulated learning, then we emphasize the theoretical frameworks, and examine the barriers. Findings from this study revealed six primary barriers: scarcity of time, disregards within the curriculum and assessments, lack of training, opposing teacher views, lack of resources, and students' resistance toward self-regulated learning. Thus, with the support of current literature surrounding remedying these obstacles, we conclude our review by qualitatively analyzing the relationships between the barriers and suggest approaches toward overcoming them.

KEYWORDS

self-regulated learning, assessment, professional development, teacher questioning, science education

Introduction

The process of learning is not uniform among students. Some learners are quick to latch onto complex scientific ideas while others struggle a bit longer to reach the same level of understanding. No matter the time frame, when analyzing new concepts, all learners experience temporary internal standoffs where they will be tasked with the decision to either explore strategies that help them reach enlightenment, or give up entirely on the learning process (Xu et al., 2023). Students may find these situations difficult and frustrating, but as learners' minds are conditioned to draw upon their collection of strategies, they build up a routined tolerance for problem-solving similar to that of real scientists (Cleary et al., 2008). Self-regulated learning (SRL) can greatly benefit students through the hardships of learning. The Next Generation Science Standards (NGSS) place great emphasis on students' ability to draw upon their own inquiry strategies with their thoughts surrounding science and engineering practices (National Research Council, 2012). However, there is a plethora of research which dictates there is a lack of SRL taking place within science classrooms (Pintrich and Zusho, 2002; Cleary et al., 2008; Zimmerman, 2008; Cleary and Platten, 2013). Thus, it is important for teachers to give students a sense of what it means to think like a scientist, have agency surrounding their own thoughts, and be more actively engaged in their own learning process.

SRL is a goal-directed process in which learners are metacognitively, motivationally, and behaviorally active participants in their learning process (Zimmerman, 1986; Zimmerman, 1989). Most learners self-regulate their learning to some degree, but the extent to which they consciously do so differentiates achievers from underachievers (Zimmerman and Risemberg, 1997). Highly self-regulated learners often feel empowered because they believe that success in learning largely depends on their ability to effectively use and adjust strategies while engaged in inquiry (Cleary and Zimmerman, 2004). Studies show SRL is critical for success in academic learning and beyond (Boekaerts, 1999; Pintrich, 1999; Perry and VandeKamp, 2000; Cleary and Zimmerman, 2004). Many scholars argue that SRL is teachable (Cleary and Platten, 2013). Kremer-Hayon and Tillema (1999) revealed student teachers and teacher educators unanimous support for SRL as it is seen as a important skill to develop in science learning. However there is a misalignment between the two groups regarding the potential for successful implementation of SRL in the classroom. Despite the importance of SRL, many students do not effectively use SRL skills to serve their science learning (Pintrich and Zusho, 2002; Cleary et al., 2008; Zimmerman, 2008; Cleary and Platten, 2013). Thus, this study aims to explore the systematic obstacles guarding educators from teaching their students SRL strategies in the classroom.

Preceding the framing of our study's major highlights, we must first explain how our focus on SRL ties into the foundational pillars of the Next Generation Science Standards. The NGSS sees science as a set of practices that illuminates how science is done (National Research Council, 2012). The focus on practices (in the plural) helps avoid the mistaken impression that there is one approach to all science called the scientific method. The NGSS prioritizes students' active construction of conceptual knowledge via the actionable practice of 'doing' science (Haag and Megowan, 2015) because the ultimate goal of science education is to help students think more like scientists (Cian et al., 2019). The standards also call for epistemic practices that engage students in scientific thinking and reasoning (Sinatra et al., 2015). This method of teaching demands changes in how science teachers organize their instruction and how students engage in classroom activities. Miller et al. (2018) argue that "unless the field tackles significant questions around precisely how students can be active agents in knowledge construction, we will likely continue to implement learning environments that position students as receivers of scientific facts and practices, even as classrooms go on to adopt the NGSS" (p. 1053). The researchers see the connection between the NGSS goal to help students apply their content knowledge through inquiry-based learning and SRL, where students are self-seeking and self-correcting learners. Thus, fostering students' SRL skills is a necessary step to meet the demands of the NGSS.

With both the structural and cultural nuances of students' learning environments at the forefront of our research, it should be noted that participation in SRL requires individualistic skills which are unique to the student in their approach toward understanding. Once adopted, SRL can be used as a way to bridge the learning and achievement gaps among certain student populations. Therefore, fostering students' SRL skills can enhance the provision of equitable chances to experience school success. By encouraging students to take ownership of their own learning and develop SRL skills, teachers can empower them to become more self-directed learners. This empowerment can be particularly beneficial for students who may not have the same opportunities for support and resources outside of the classroom. Students who can take control of their own learning are noted to become more confident and capable learners, which can have a positive impact on their academic and personal lives (Boekaerts, 1999; Pintrich, 1999; Perry and VandeKamp, 2000; Azevedo and Cromley, 2004; Cleary and Zimmerman, 2004).

Another benefit to supporting SRL in the classroom lies within discussions of equity. Equity is typically mentioned as a means toward providing scholarly opportunities for all students to succeed, and SRL has the capacity to facilitate this. SRL can enhance students in systematically thinking through their approaches to problems of inequity and stimulate more successful learning experiences (Santoso et al., 2022). When students master SRL, they are more equipped to know what they need and actively seek help. This makes it much easier for teachers to know what to provide students throughout their learning process, which can lead to a more holistic and equitable learning experience for all students.

With the end goal in mind to reform science classrooms in a manner that streamlines the integration of SRL, it is important to highlight the obstacles so that researchers may find so as to overcome them. Simply put, knowing the obstacles that infringe upon a teacher's ability to incorporate SRL in the classroom can help to diminish these barriers and support SRL being more consistently enacted in classrooms. With a multitude of potential learning gains in mind, this study aims to find and present tangible recommendations for positive reform in this regard. The researchers of this study assert that if the science education community wants teachers to adopt SRL strategies in the classroom, the community needs to make SRL a more explicit focus within the field of science education research. With the knowledge we acquired in this study, we hope that readers of this work will be more equipped to differentiate professional development (PD), classroom practices, or other notable entry options with practical approaches "around" these common obstacles.

Purpose of the study

The purpose of this study was to investigate the obstacles that inhibit science teachers from implementing SRL as a common instructional practice. Common instructional practices of interest were specific to classrooms with an allotted instructional time rather than tutoring or other special programs that do not count toward the mandated hours of instruction for a governmentally mandated course of record. To explore this topic the researchers of this study reviewed various articles on SRL. These articles ranged from theoretical works that cited other empirical studies to intervention inquiries that were followed by an analysis of SRL classroom practices. Additionally, the researchers excluded articles that did not provide thoughts toward why the teachers may lack SRL classroom implementation. With these factors at the head of our exploration, our review is guided by the question: What are the barriers that prevent science teachers from fostering their students' SRL skills?

Theoretical frameworks

This literature review is guided by two frameworks: Zimmerman's cyclical phases model of SRL (Zimmerman, 2000; Zimmerman and Moylan, 2009), and model of learning organization (Senge, 2006).

Zimmerman's cyclical phases model

The Zimmerman's cyclical phases model of SRL includes three phases: forethought, performance, and self-reflection. In the forethought phase, learners analyze their learning tasks, set goals, and plan to achieve the goals. Learners' self-motivation beliefs affect the way they set goals and plan for their learning. During the performance phase, learners use different strategies to monitor their learning process. The self-reflection phase is when learners evaluate their performance and identify possible causes of their learning outcomes. The way learners attribute their success or failure affects their motivation and learning behaviors in the next SRL cycle (Zimmerman and Moylan, 2009).

Model of learning organization

This model consists of five disciplines: personal mastery, improving mental models, establishment of a shared vision, team learning, and systems thinking (Senge, 2006). Personal mastery refers to self-realization that breaks through one's own limits or skillfulness, which includes competence and spiritual growth. A person with personal mastery knows their desired future and knows how to move toward it. The mental models are a set of beliefs that affect how we understand the world and how to act. Positive changes in organizations can only be achieved and sustained when members of the organizations believe that the changes are reasonable. For instance, science teachers will not enact SRL if they think SRL does not support science learning. The ability to establish a shared vision, which is a shared picture of the future an organization seeks to create, is critical for any organization. For example, if all science teachers at a school share a vision to leverage SRL in science classrooms, there is a much higher chance that each of the teachers implement SRL. Team learning leads to collective intelligence of a group that is higher than the sum of the individuals' wisdom. For instance, team learning occurs when teachers exchange ideas and resources to make their teaching more effective. System thinking means integrating other cultivations into one and seeing the interrelated actions instead of isolated parts (Senge, 2006).

Methods

In 1986, scholars had distinguished SRL from metacognition (Panadero, 2017), so articles for this review were selected from January 1986 to March 2022 (when the authors started this literature review). Four databases were used to search for articles: APA PsycInfo, ERIC, PD collection, and Education Research Complete. The researchers used a selection of key terms (e.g., "self-regulated learning" and "teacher question*;" "self-regulated learning" and "assessment*;" "professional development," "teacher questioning" and "science education") to run their initial search from the four databases. The researchers reviewed the titles of these articles selecting only those which reflected those same key terms. Then, the researchers reviewed the abstracts of each of these articles using both a key term search and a text dependent reading analysis to find articles that focused on SRL implementation; many of which specifically analyzed SRL professional development. Subsequently the researchers ran an advanced search on the articles using the key terms "self-regulated learning" and "science." The articles were then individually analyzed by reading through the abstracts to ensure that the studies were empirically focused on SRL. The researchers then decided to eliminate the articles focusing on assessments as this was not of primary relevance to the study. The remaining articles were then reviewed further by reading through the findings and discussion for details surrounding the obstacles affecting SRL implementation. Summatively the articles and book chapters were chosen by reading the titles, the abstracts, checking for the presence of keywords, and screening to ensure they meet the following selection criteria:

> · Focused on SRL.
> · About science learning, science teaching, and/or science teachers (pre service or inservice).
> · Peer-reviewed articles or book chapters.

Once the number of articles were condensed, the researchers conducted two coding processes: *a priori* coding and emic coding processes. The *a priori* codes were developed based on our prior knowledge of the literature (e.g., lack of time, curriculum, teachers' view). The emic codes emerged from the reviewed articles during the analysis (e.g., student resistance, formative assessments). Finally, the researchers conducted pattern coding. We grouped the *a priori* codes and the emic codes based on the meaning of the codes. Using the groups of codes, we developed themes describing the obstacles of enacting SRL. In developing these themes, we aimed to stay as close to the sentients of the codes as possible (Miles et al., 2014). All the steps of the thematic coding process led to six obstacles of enacting SRL in science classrooms.

Findings

The thematic coding process led the researchers to pinpoint six major obstacles (Table 1) which appeared to block the adoption of teachers' incorporating SRL in science classrooms: (1) Lack of time to address SRL, (2) Deficiency of SRL in Curriculum & Assessments Resources, (3) Inadequate Teacher Training on SRL, (4) Teachers Disconfirming Views of SRL, (5) Scarcity of Resources for SRL Application, and (6) Student Resistance to SRL. Table 1 includes the citations of the 15 reviewed articles and the obstacle(s) that the articles discussed. The subsequent sections of this article have expounded upon these obstacles more deeply.

Lack of time to address SRL

Four out of 15 studies declared that teachers feel as though they do not have sufficient time to address SRL (Davis and Neitzel, 2011; Vandevelde et al., 2012). For example, Vandevelde et al. (2012) expressed that a *lack of time*, work pressure, and diversity among pupils are reported as the most important barriers for the

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TABLE 1 Review of the literature on obstacles that prevent science teachers from Fostering their students' SRL skills.

Study	Time	Curriculum and assessment	Training	Teachers' belief	Resources	Student resistance
Jayawardena et al. (2019)		x				
Fluckiger et al. (2010)			x			
Davis and Neitzel (2011)	x	x		x		
Klug et al. (2011)			x			x
Dignath-van Ewijk and van der Werf (2012)			x		x	
Clark (2012)		x	x			x
Michalsky (2012)			x	x		
Vandevelde et al. (2012)	x	x	x	x	x	x
Zimmerman and Schunk (2012)			x	x		
Heritage and Heritage (2013)		x	x			x
Peeters et al. (2014)		x		x	x	
Spruce and Bol (2015)	x	x	x	x		
Panadero (2017)	x	x	x	x		x
De Smul et al. (2018)			x	x		x
Cleary et al. (2022)			x	x		x

implementation of SRL practices. To implement SRL in science classrooms, teachers need time to plan, to create opportunities for students to engage in SRL, and to give feedback to students (Dignath-van Ewijk and Van der Werf, 2012). Nevertheless, science teachers often prioritize other teaching demands instead of SRL. Furthermore, fostering students' SRL skills requires long-term commitment to see the results of the work. The development of SRL skills occurs gradually because SRL is a complex process that involves several interrelated skills, such as goal-setting, monitoring, and self-evaluation (Zimmerman, 2002; Schunk, 2012). Besides providing students with ongoing opportunities to practice, teachers need to provide feedback and support. Some teachers may make a little time for SRL at the beginning of a semester but cannot maintain the work throughout the school year due to other teaching responsibilities such as preparing students for state tests.

Deficiency of SRL in curriculum and assessments resources

Another common impedance extracted from these articles is the lack of SRL explicitly embedded within science curricula and assessments. This obstacle was addressed in eight out of the 15 different articles. Peeters et al.'s paper Peeters et al. (2014) section on educational innovation declares "if the implementation of SRL classroom practices is regarded as an exemplification of educational innovation, it first needs to be articulated as a clear objective" (p. 1967). Through this revelation the scholars surfaced the potential implicating factor that while we aim to create more self-regulated learners in science classrooms, there may be a misalignment in the approach as the curricula presented may not explicitly align with the materials being used by students. In short, when science curricula do not state the role of SRL in science learning, teachers may not have the buy-in to make SRL translate into their own classrooms. Thus, the lack of alignment between curricula, expected teaching practices, and assessments may prevent establishing a shared vision of SRL. This could consequently weaken an educational system because of the disregard toward a shared goal (Senge, 2006).

Inadequate teacher training on SRL

The most common of the six obstacles noted among the articles was the lack of teacher training on SRL. Twelve of the 15 articles expressed this as a common barrier. Studies have demonstrated that teachers lack both content knowledge and pedagogical content knowledge about SRL (Dignath-van Ewijk and Van der Werf, 2012; Spruce and Bol, 2015). Peeters et al.'s study Peeters et al. (2014) has brought attention to teachers' own lack of SRL understanding and implementation in their daily attempts toward problem solving to be the central obstacle for excluding SRL in the classroom. Additionally, teachers demonstrated gaps in knowledge, particularly around goal setting for a task and evaluation after a learning event. Many teachers may even be unaware of the gaps in their SRL knowledge and classroom instruction and therefore do not recognize the need for professional development in this area (Spruce and Bol, 2015). Cleary et al. (2022) recounted the voices of 19 teachers who felt that they lacked training or support in SRL to turnkey SRL strategies in their classrooms as the authors declared, "this gap has prompted researchers to develop and evaluate the effectiveness of SRL-promoting PD initiatives with teachers" (p. 2).

Teachers disconfirming views of SRL

How science teachers position SRL in the space of learning was another important point of consideration toward understanding the common SRL implementation obstacles. This barrier was presented nine times within the 15 articles reviewed. The literature revealed that science teachers' beliefs regarding different aspects of SRL such as the role of SRL in science learning, their ability to foster SRL in students, and students' ability to enact SRL strategies all played a part in how they positioned and implored SRL strategies in the classroom (Michalsky, 2012; Peeters et al., 2016; De Smul et al., 2018). Therefore, in order for teachers to implement SRL in science classrooms, they first need to believe that SRL can support students in constructing their knowledge (Spruce and Bol, 2015).

Scarcity of resources for SRL application

Working toward getting students to successfully implement SRL requires more than just time and teacher effort. Researchers noted several SRL interventions where experts from the field of science education served as a sort of task force to help students understand and adopt SRL on their own (Araka et al., 2020). In this regard, teachers can act as collaborators, or more practically an available resource, for their students as they work together to identify issues in students' learning to develop SRL skills. In other cases, human capital may not be the specific resource in deficit; rather, a lack of financial backing to purchase custom made software systems specifically designed to push SRL thinking strategies may be the point of need (Wong et al., 2019). One research study showed how an intervention with technology to assist students' development of SRL utilized a software program that was successful (Peters-Burton et al., 2023). It may be that the lack of proper financial support is a major obstacle to successfully implementing SRL as these software programs may not be readily available at some schools. Nevertheless, regardless of whether the resources for assisting in the development of SRL skills are in human form or not, resource scarcity in general emerged three times within the reviewed studies as a common hindrance toward adopting SRL strategies in the classroom.

Student resistance to SRL

As previously discussed teachers fostering SRL within the classroom is not the sole contribution to students implementing SRL in the classroom, the students themselves have to be motivated to utilize the strategies being presented to them (Cleary et al., 2008; Buzza and Allinotte, 2013; Cleary and Platten, 2013). Therefore, student resistance is another common obstacle of concern mentioned seven times throughout the review of the 15 articles. These articles further enhance the idea that while there are multiple strategies that teachers can use to support students developing their own SRL skills, there is a great deal of SRL which solely relies on the student. At an individual level, students must take ownership of and work toward cultivating SRL skills. Nevertheless, this can be hard to master when many students prefer to rely on their teachers to direct their learning because those students are not used to taking responsibility for their learning (Cleary et al., 2008; Cleary and Platten, 2013). Traditional approaches to instruction do not require students to be active in their learning. Thus, many students do not know what to do when given the opportunity to take control of their own inquiry process and make decisions about what and how they want to learn. Those students need additional encouragement and support to make the transition to develop SRL behaviors. Many authors (e.g., Klug et al., 2011) have referenced instinct student motivation as a necessary factor for full alignment of SRL adoption, which directly relates to student resistance.

Discussion

The researchers drew upon articles which attempted to provide rationale for a lack of classroom SRL implementation. Upon analyzing these common barriers, the researchers discovered six main causes: (1) time, (2) curriculum and assessment, (3) lack of training, (4) belief, (5) limited resources, and (6) resistance from students. After scaling it down to these six thematic causes further analysis exposed genuine relationships between these obstacles, and the further analysis also helped to identify which of these six was the most approachable for science teachers to address SRL. Thus, the following sections will be utilized to denote these connections and to employ noteworthy suggestions to circumvent these SRL deterrents.

Noteworthy relationships among the obstacles

The researchers noted a majority of connections between curriculum and assessment with other obstacles. Curriculum and assessments have long been a major focal point in education (Rudolph, 2002). Thus, teachers referencing curriculum and assessment items to set the tone of importance for classroom considerations is not a foreign concept. The chances of a teacher disregarding SRL in the classroom increases drastically if a teacher does not see a connection to SRL within the curriculum items (Davis and Neitzel, 2011). In other cases, there are times in which teachers' beliefs and misconceptions about what should be taught in a classroom inform curriculum and assessment (Wallace and Priestley, 2011). Avocational curriculum and assessment writers often render the feedback of teachers and implementers to help design quality curriculum products. In the world of science education, research tends to functionalize the best practices present in curriculum. However, when this research unveils a misalignment between teachers' belief and classroom instructional practices there have been times in which curriculum writers design curriculum to not only inspire student learning, but also enlighten teachers as well (Wallace and Priestley, 2017). Therefore, if curriculum and assessment creators assume there is already a general credence of SRL among educators, then curriculum items and training may be void of SRL. On the other hand, once SRL is part of science curricula and assessments, it is more likely that school districts provide more resources for SRL enactment and science teachers make more time for SRL.

The lack of SRL within science curricula and assessments is not only linked to teacher beliefs, but is also teacher training. Just as Peeters et al. (2014) implied if the curricula and assessments lack attention to SRL we should not expect to see it in teachers' classrooms, or for that matter maximed as a point of regard in teacher training. This underlying factor was raised again within the discussion of student resistance. Curriculum and assessment are not only held in a position of focus with teachers, it is also a center of attention among students (Gurung et al., 2010). Thus, students can resist being taught SRL because there is a clear lack within curriculum and assessment items.

Conclusively a deeper investigation into each of these obstacles led us to the following revelations. Firstly, if SRL is not embedded into science curricula, teachers and students alike may have a lack of incentive to subscribe to instruction pertaining to SRL. Secondly, for teachers who aim to attempt SRL within their classrooms when there is a lack of support either in funding, human capital, or within the curriculum itself, teachers may feel they have to triage SRL and place it on the back burner. With this approach even teachers with the best intentions for utilizing SRL may be scarce on time for incorporating SRL in their classrooms. Thirdly, teachers who are not trained on SRL may find themselves in situations where they feel overwhelmed about teaching themselves SRL strategies that can be turnkeyed with their students. Additionally, since teachers can support each other, a shared vision, which is stated in science curricula and translated to assessment items, will promote team learning that might contribute to overcoming the barriers aligned with lack of training and time. Finally, based on the model of learning organization (Senge, 2006), system thinking should contribute to eliminating the barriers.

Suggestions for overcoming the barriers

Time

One way to save instructional time is to integrate SRL into other classroom activities. For example, Peters-Burton et al. (2023) integrated SRL with computational thinking as problem-solving processes to facilitate student engagement in data practices. Another way is to make sufficient time for SRL at the beginning of semesters and benefit from it in learning term (Peeters et al., 2014).

Teachers' beliefs

Teachers believe in the role of SRL, in their ability to foster SRL in students, and in students' ability to enact SRL strategies can be improved by (1) fostering teachers' understanding of SRL (Kramarski and Michalsky, 2009), (2) supporting teachers with self-efficacy for teaching SRL (Cleary et al., 2022), and (3) introducing SRL to preservice science teachers during teacher preparation programs (Kramarski and Michalsky, 2015; Tran et al., 2022). As the model of learning organization states, teacher beliefs are a filter for their pedagogical decisions and actions (Senge, 2006); shifting science teacher beliefs regarding SRL is a necessary step for implementing SRL in the classroom.

Training

Many studies suggest offering more SRL-promoting professional development for science teachers (Dembo, 2001; Gordon et al., 2007; Kramarski and Michalsky, 2009). Or it would even be better to integrate SRL into science teacher preparation programs. A few existing studies show that it is possible and effective to embed SRL into teacher education programs (Kramarski and Michalsky, 2015; Tran et al., 2022). In terms of growth of an organization (Senge, 2006) recounts that it is only through individual learning that organizations can learn. Thus, integrating SRL into science teacher preparation programs and providing SRL PD for science teachers becomes increasingly important.

Curriculum and assessment

The misalignment of shared goals is a rather common theme in the line of science curriculum and assessment research. Even at the level of large-scale science assessments, there are multiple frameworks that detail how content and cognition dimensions must merge in scientific inquiry (Kind, 2013). However, because specificity lacks in how the two dimensions are supposed to work together; stakeholders often make test items and scales in isolation while fragmenting one dimension at a time leaving teachers to make tough decisions regarding what the focus of instruction should be. Nevertheless, science learning requires students to couple their content knowledge and SRL strategies to think through a problem and reach their learning goals. This can be hard to do when a teacher stands at the crossroads of selecting a focal point of instruction without explicit direction regarding how the content and cognition are supposed to couple. It then becomes increasingly understandable to see how these inconsistencies in assessments trickle down to classroom instruction. Renzulli (2021) confirms this in their analysis of how historically standardized testing has brought about "low level pedagogy that is highly prescriptive and didactic in its approach toward learning" (p. 46). Ultimately this amounts to a curriculum which emphasizes recall information which could come up on the next round of standardized tests.

Since the development of SRL skills requires consistent effort and practice over an extended period of time, a more cohesive inquiry led to the larger examination of educational administration. Looking past the level of classroom instruction, the science community must recognize that support from the school and district levels is needed to make it part of the curriculum. Therefore, while educational supervisors are typically trained to understand how the learning process superseded the sole accumulation of facts, deficiencies of SRL implementation in curriculum and assessment resources can also lead to lack of support at the school and district level for implementing SRL (Peeters et al., 2014). One reason science teachers do not have motivation to integrate SRL into instruction is that the current science curricula and standards do not clearly define the role of SRL in science learning. Thus, teacher educators should emphasize research that shows how SRL supports achieving learning objectives in science curricula (Boekaerts, 1999; Pintrich, 1999; Perry and VandeKamp, 2000; Cleary and Zimmerman, 2004). Regarding the obstacle in assessment, which tends to focus on low level pedagogy, one suggestion is to use machine learning to support science learning assessment. Research shows that leveraging machine learning in assessment can better assess students' thinking and learning processes (Zhai et al., 2022).

Student resistance

There are three ways to overcome student resistance to take responsibility for their learning: (1) improving students' understanding of the benefits of SRL (Cleary and Zimmerman, 2004), (2) providing opportunities for students to see the results of their SRL efforts (Buzza and Allinotte, 2013), and (3) creating supportive and encouraging learning environments (Peeters et al., 2014).

Scarcity of resources

Teachers might be able to minimize the impact of the lack of resources for SRL implementation by being creative with limited resources and by leveraging existing resources to support SRL (Cleary et al., 2022). One free resource is SPIN (Science Practices Innovation Notebook) - an electronic lab notebook that facilitates SRL enactment (Peters-Burton et al., 2023, 2024).

Most approachable obstacles to address SRL

Studying the specifics of all six of the obstacles and inspecting the connections between them helped the researchers to see tangible areas of opportunity within the obstructions. Trying to reposition both teacher and student antagonistic mindsets to SRL can be seen as impossible barriers to overcome. However, new ways of thinking emerge as one realizes there might be a similar cause for both groups' oppositions which can be shifted with practical adjustments to the curriculum and assessment items. Simply put, if the cause of contradistinction toward SRL is linked to the lack of SRL being explicitly placed within curriculum and assessment items, then it should behoove the science education community to respond by placing SRL into these spaces. While successful SRL interventions have been noted from science instructors who took the time to teach both SRL strategies and required curriculum (Nagle et al., 2016), However, the integration of SRL should be more simplified for teachers so that they are not operating as though SRL and the required curriculum are separate entities. Thus the researchers positively appraise more integrative methods of SRL into science curricula and assessments (Chen and Bonner, 2019). Another area that was noted as an approachable means to review is training. Research showed a lack of teacher understanding about how to implement SRL effectively (Dembo, 2001; Gordon et al., 2007; Kramarski and Michalsky, 2009), so training alongside continuous practices that serves as a campus priority can also be noted as a means toward correcting SRL implementation incognizance.

Conclusion, recommendations, and limitations

This literature review examines the obstacles that hinder the implementation of SRL in science classrooms. Since the obstacles are intertwined, to completely facilitate the implementation of SRL, we will need to address all the interrelationships within them. SRL skills are pedestoled as a fundamental tool in scientific inquiry, thus it is important to denote classroom approaches that will support teachers toward advancing their students in this area. Teaching students through SRL is a crucial strategy toward empowering students to mature their own capabilities in inquiry-based problem solving. Therefore, it is worthwhile to research potential barriers commonly noted in classrooms which might infringe upon teachers' abilities to practically apply SRL. Many studies unraveled the benefits and best practices of teaching SRL, but there were very few studies over the past two decades emphasizing the common barriers science teachers embark upon that prevent them from pragmatically applying it. Thus, we hope that this study acts as the catalyst needed to push other researchers to further investigate the obstacles preventing teachers from utilizing SRL. Additionally, some may note teachers and educational leaders lack of autonomy involving curriculum decisions. However, training in SRL is one of the most practical approaches of causes uncovered because upon designing PD addressing SRL, teacher educators should be able to account for these obstacles within their PD structure. For instance, a PD on SRL accounting for time may allow its participants to role play teaching scenarios where they are held to strict pacing regulations while utilizing SRL techniques. Intuitively this will give them a more realistic feel for how using these newly learned skills will feel in an actual classroom. Finally, with the exception of Chen and Bonner (2019) who derived a framework for incorporating SRL into classroom assessments, looking into the most approachable obstacles allowed the researchers to see the discrepancies between the wealth of research focusing on localizing SRL strategies and the lack of literature naming an clear model as to how these strategies are successfully positioned into curriculum and assessment. Therefore while the researchers distinguish the integration of SRL into science curricula to be one of the most approachable measures toward seeing teachers successfully adopt SRL strategies into the classroom, they recognize the need for the science community to further investigate this area of research.

Finally, the researchers denote two major limitations in this study. Even though the authors reviewed more than 15 articles in this literature review, only 15 papers were reviewed systematically for the obstacles; the other papers were reviewed for suggestions to overcome the obstacles. Second, the authors reviewed only articles that were published in English.

Author contributions

JD: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing, Validation. HT: Conceptualization, Data curation, Methodology, Software, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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