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Self- and Socially-Regulated Learning in Middle School Science Classrooms: A Multiple Case Study

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Understanding the Relationship between Questions and Student Self-Regulation in Secondary Science Classrooms: A Systematic Review

Followed by

Self- and Socially-Regulated Learning in Middle School Science Classrooms: A Multiple Case Study

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Virginia Commonwealth University

by

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Dedication

This dissertation is dedicated to my former students and education colleagues. You all inspired this line of study and helped encourage me to pursue my dreams.

Table of Contents

Understanding the Relationship between Questions and Student Self-Regulation in Secondary Science Classrooms: A Systematic Review

Abstract

Questions asked in science classrooms drive student inquiry and discourse and lead to cogeneration of science understanding and sensemaking. However, the influences of questions specifically on student self-regulated learning (SRL) in the classroom is underexplored. Given the expansive literature bases of questioning in science classrooms and student SRL in science, this systematic review aims to explore the intersectionality of these two literature bases, in the specific context of secondary science classrooms. Twenty-eight studies were included in the review and revealed insights as to how questioning and SRL are studied in secondary science classrooms and how questions can influence student SRL. Given the exploratory nature of systematic review, lines of future research are extensively discussed, as well as research and practical implications.

Keywords: Self-regulated learning, questioning, science

Understanding the Relationship between Questions and Student Self-Regulation in Science Classroom Contexts: A Systematic Review

Self-regulated learning (SRL) is a vital underlying component of learners' motivation and academic success (Hattie et al., 1996; Pintrich, 2000; Veenman, 2017). Pintrich (2000) defines SRL as an:

> active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior in the service of those goals, guided and constrained by both personal characteristics and the contextual features in the environment. (p. 453)

Teachers play an important role in the development of students' SRL by creating opportunities for students to practice self-regulation; that is, practice taking ownership of their learning in the classroom (Korinek & deFur, 2016). This emphasis on developing students who are able to independently plan, monitor, and control learning behaviors and thinking processes [classroom level learning outcome].

Self-regulated learning in classrooms is primarily viewed through a social-cognitive perspective (e.g., Hoyle & Dent, 2018; Zimmerman, 2013). Social-cognitive theory is a useful framework to explain how human interactions affect individual learning processes (Bandura, 2001; Usher and Schunk, 2018). Specific to SRL, social cognitive theory posits that students' SRL processes, such as planning and monitoring, occurs through an iterative process influenced by interactions with teachers and peers. Further, it recognizes students' interpretations of these interactions in relation to their own thoughts and motivations. From this social-cognitive perspective of SRL, it is then imperative to study individual students' SRL processes in classroom contexts, as they provide critical social interactions for students (Martin, 2004).

Narrowing the focus to science classroom contexts, SRL is uniquely supported by the fundamental tenets of scientific inquiry. Scientific inquiry, at its core, is characterized by a disciplinary way of thinking and persisting with the shared goal of advancing scientific knowledge (Bell, 2009; Novak, 1964). Engaging in scientific inquiry is facilitated by intrapersonal qualities such as curiosity and interest about the natural world and effectively investigating questions about science phenomena. Scientific inquiry can be broken down into a set of disciplinary practices that are core to recent science education reforms (e.g., National K12 Framework for Science Education; National Research Council, NRC, 2012), such as asking scientific questions, constructing explanations based on evidence, and evaluating and communicating findings from investigations (National Research Council, 2000; Padilla, 2010). Engaging in these disciplinary, inquiry-based science practices requires students to engage in all stages of SRL: planning (e.g., developing investigable questions, designing procedures for an experiment), monitoring (e.g., reliably collecting data), and reflecting (e.g., reporting and explaining errors and unexpected findings). Therefore, scientific inquiry spaces are an ideal context to examine and better understand how to develop students' SRL skills.

In line with the premise that SRL is a key feature of science inquiry, the vision for science education outlined in recent reforms position students as active participants in the classroom. Students act with ownership over their learning, expressed through meaningful sense-making to construct knowledge as they ask questions, gather evidence, and communicate and revise explanations (Benedict-Chambers et al., 2017; Chin, 2007; Odden & Russ, 2019; Smart & Marshall, 2013). This systematic literature review focuses on asking questions as a high-leverage pedagogical practice that is both modeled by the teacher and enacted by students in science classrooms. This natural tendency for questioning, by both the teacher and student, in scientific inquiry spaces (Downing and Gifford, 1996; Lotter, 2004) makes it a uniquely ideal context for researchers to study the role of questioning on student SRL. This review will therefore examine the relationship between questions (posed by the teacher and/or students) and student self-regulation in science classrooms.

Relevant Literature

Although science classrooms, and more specifically interactions in which questions are posed in science classrooms offer a rich context to better understand students' SRL, few studies to date explicitly examine science questioning and SRL together. Rather, the current state of the literature is largely characterized by studies that focus on the role of the teacher (e.g., Manz & Renga, 2017; Morris & Chi, 2020; Murphy et al., 2018) and/or student questions (e.g., Gilles et al., 2012; Chin & Osborne, 2008; Nieswandt et al., 2020) in science classrooms or focus primarily on students' self-regulation processes in science classrooms. Therefore, the first part of this literature review will synthesize the relevant background literature on questioning in science classrooms and student SRL in science separately.

Questions in Science Classrooms

Teachers ask questions to their students in a multitude of formats including whole class, small groups, and individuals (Sandoval et al., 2020), and modalities including both spoken and written on activities and assignments. Likewise, students add to the amount and nature of questions asked in the classroom. In this literature review, we focus on spoken or oral questions employed by teachers and students in the classroom. Verbal questions posed in science classrooms and their resulting conversations are unique in that they often provide real-time feedback to the teacher and/or students regarding progress and comprehension (i.e., providing information to someone about how well they are working through and understanding their work;

Hattie & Timperley, 2007; Wisniewski et al., 2020).

Questions Posed by the Science Teacher

A large body of literature demonstrates that science teachers' questions fall along a continuum, characterized by more sophisticated question strategies (e.g., higher-order questions, focusing on providing evidence and reasoning) that stimulate deeper cognitive reasoning on one end, to more closed-ended questions that require students to recall information (e.g., Smart & Marshall, 2013; Manz & Renga, 2017; Murphy et al., 2018). These questions can target naming phenomena, scientific practices, and recalling science knowledge.

Science teachers frequently interact with students by asking several types of questions that are often designed to create opportunities for students to engage in scientific discourse (REFERENCES). For example, teachers' questions help guide students to construct their own knowledge of the content and practice science skills in a guided manner (Benedict-Chambers et al., 2017; Chin, 2007; Hmelo-Silver et al., 2007). Therefore, questions play a crucial role in the development of students' SRL development and science learning.

Student Questions in Science Classrooms

A related body of research has also examined the types of questions posed by students in science classrooms. For example, Chin and Brown (2010) studied student questions in an eighth-grade science class. They identified the types of questions students were asking and what purpose it provided in knowledge construction. They found that factual and procedural questions were associated with surface-level learning, whereas wonderment questions (i.e. those that delved into predicting, analyzing, and planning) were associated with deeper learning. They also found that teachers could impact student-initiated questions. Wonderment questions were not always spontaneous, but could be easily elaborated on by students when prompted by the teacher. Also, problem solving activities stimulated more wonderment questions than teacher-directed activities. Lastly, wonderment questions generated more class discussion than factual and procedural questions. Like teacher-generated questions, student questions can be categorized in a variety of ways and have a large impact in the science classroom.

Given the variety of questions asked in the classroom, several qualitative coding schemes have been developed to help researchers study questions in the classroom. Qualitative coding of classroom conversations is a powerful tool in analysis. Questions can be coded by levels of sophistication (e.g., Smart & Marshall, 2013), the purpose of the question (e.g., Benedict-Chambers et al., 2017), and student outcome of the question (e.g., Manz & Renga, 2017). Developing codebooks around teacher questions can show how students construct their thinking and how teachers can deliberately help that through the scaffolds their questions provide.

The purposeful questions that teachers and students will ask in their classrooms support science learning. Students internalize the disciplinary ideas and practices of science and engage deeply in learning activities. This internalization can not only support science learning but self-regulation development. In the next section I will overview how verbal feedback, questions, and student self-regulation are related.

Feedback

Feedback can be defined as any information provided to someone about their progress (Hattie & Timperley, 2007; Wisniewski et al., 2020). In the "Model for Feedback" provided by Hattie and Timperley (2007), feedback serves multiple purposes to help students make connections between one's current understanding and the desired goal. Teachers directly help by first providing developmentally appropriate goals and then assisting with useful strategies and feedback. Effective feedback can assist with identifying goals ("feeding up"), their current level of progress ("feeding back"), or how to get to the next step ("feeding forward"). With each of these, feedback can be provided at four levels: 1) Task, 2) Process, 3) Self-Regulation, 4) Self-Level, each increasing in complexity, and level of internalization (Hattie & Timperley, 2007). The complexities of how feedback can be characterized mirror the complexities of the social-cognitive framework existing naturally in the classroom setting.

To help show what these different kinds of feedback look like in situ, Brooks and colleagues (2019) created a scaffolding rubric for teachers to give more advanced feedback. They recognize that more advanced students need process and self-regulatory feedback and provide prompts for teachers to use. In their rubric, *task-level feedback* was largely teacher-directed comments given quickly. *Process-level feedback* was more student mastery driven, making them more complex, but still statements. Lastly, *self-regulatory-level feedback* was more delayed, and all in the form of questions. Therefore, questions asked in the classroom provide feedback to students.

Feedback has also been shown to directly affect self-regulated learning development. In the review by Butler and Winne (1995), they point out that the monitoring process of SRL utilized internal feedback, but that external sources of feedback, such as encouragement and affirmation, can act as a catalyst for the internal feedback of SRL. For feedback to serve this critical purpose, it needs to be given throughout the activity, as opposed to just after it is completed. Lastly, as researchers, to be able to study feedback's full effects on SRL, analysis at a smaller grain size is crucial. Given this call for feedback throughout the process, Nicol and Macfarlane-Dick (2006) outline principles of good feedback to support SRL. They include clarifying what good outcomes are, helping students self-assess, encouraging student and teacher dialogue, and fostering positive student motivation and self-esteem. There are aspects that mediate how self-regulatory feedback is perceived by the student, including the capability to create internal feedback to self-assess later, willingness to invest effort, and confidence (Hattie & Timperley, 2007). In summary, theoretical models and empirical research indicates that teacher feedback helps to increase students' SRL development.

Self-Regulated Learning

The field of self-regulation is also vast. Individuals can regulate emotions, behavior, and learning processes (Scholar et al., 2018; Usher & Schunk, 2018). For the scope of this study, cognitive and metacognitive facets of SRL were focused on given the social-cognitive framework adopted and its strong ties to both classroom questioning and SRL. In the following section, I will be reviewing the literature of these related but distinct fields of questioning and SRL in science classrooms.

Self-Regulated Learning Frameworks and Definitions

Self-regulated learning specifically refers to the role of regulation and metacognition in the learning environment and academic development of students (Dinsmore et al., 2008). SRL has been studied through various frameworks including cognitive, motivational, behavioral, environmental/contextual, and affective/emotional. Cognitively, SRL is studied through discreet acts with the purpose of understanding the content (Panadero, 2017). These frameworks often look at composite data of specific student learning strategies such as highlighting, summarizing, and making study guides. Metacognitively, researchers focus on students' processing and organizational skills centered around how they learn (e.g., setting goals and planning for them; Pintrich, 2000). Motivational SRL, grounded in the social-cognitive framework, aims to understand what drives students to independently move through learning tasks (Zimmerman, 1989). With this motivational framework, SRL is positively associated with self-efficacy, task value, and mastery-oriented learning approaches (Pintrich, 1999). Behavioral SRL focuses on how students regulate their actions with the purpose of doing the right thing including following deadlines and directions (Hoyle & Dent, 2018). Environmental facets of SRL, also referred to as contextual factors (Pintrich, 2000), works with how students attempt to control their surroundings to maximize their learning (e.g., time maintenance, quiet workspace). Lastly, emotional or affective facets of SRL address students' feelings as influential factors in the learning process (e.g., anxiety, excitement, interest; Boekaerts, 1996). It is noteworthy to mention that while we can discuss these factors in isolation, some SRL frameworks take multiple dimensions into account (Panadero, 2017). A widely used framework of Self-Regulated Learning is outlined by Zimmerman (2002): 1) Planning, 2) Monitoring, 3) Evaluating. Pintrich and Zimmerman's frameworks focus on motivational factors, but also highlight cognitive and metacognitive factors, while Boekaerts' model emphasizes the role of emotion in cognition and regulation (Panadero, 2017). This recognition of the multidimensionality of SRL has led scholars to believe that SRL will be independently and contextually different (Zimmerman & Schunk, 2011).

Further, each of these SRL frameworks can progress through four levels as students develop: 1) Observation, 2) Emulation, 3) Self-Control, 4) Self-Regulation. These levels of SRL develop naturally and through outside sources, such as feedback (Zimmerman, 2013). In a study by Perry and colleagues (2002), classrooms in which teachers promoted SRL development typically had the following pedagogical strategies: offered student choices; gave students opportunities for self-control, self-evaluation, and peer- evaluation; gave supports to students from the teacher and peers; and gave evaluation in a non-threatening and mastery-oriented manner. In research, SRL is typically assessed by individual self-report measures, probing how students believe their SRL development and skills are progressing (Dinsmore et al., 2008). Also, recognizing that SRL is defined, conceptualized, and ultimately operationalized in a variety of ways, researchers must be open to a broad search when looking for SRL methodological examples (Boekaerts & Corno, 2005; Zimmerman, 2008). By exploring the classroom contexts that can foster students' SRL development in different ways, we can better understand how to create classroom environments that support students to be more self-driven learners. This larger focus on helping students take ownership over their learning can have a wider and stronger impact than simply targeting how students progress in content mastery.

Measuring Self-Regulated Learning

With self-regulation encompassing so many aspects of learning, researchers have developed many ways to research students' SRL. Self-report surveys, such as the Learning and Strategies Study Inventory (LASSI) and the Motivated Strategies for Learning Questionnaire (MSLQ), are common. The surveys will have students remember, reflect, and self-judge their own regulation. They are advantageous for being able to capture the covert, or internal, aspects of SRL, but lack the ability to capture SRL events happening in real-time with an objective eye (Cleary & Zimmerman, 2012). This has led researchers to develop think-aloud protocol (TAP) and trace measures. These measures rely on coding video and audio data with a list of SRL indicators (Cleary & Zimmerman, 2012). These methodologies are helpful for identifying objective and observable indicators but can lack the ability to draw out covert aspects of SRL.

Self-Regulated Learning and Student Outcomes

Extant literature makes substantive claims that using self-regulatory practices is related to academic achievement, with the strongest association being in science classrooms (Dent & Koenka, 2016). A particular focus of SRL strategies that secondary (grades 6-12) students employ should be taken. With more specialized courses and rigorous testing, variation in academic achievement is more likely to be caused by the variation in the use of SRL strategy (Dent & Koenka, 2016). In a mixed-methods case study, Cleary and Platten (2013) saw that high school biology students saw more academic success and gains when they used more SRL strategies such as studying well in advance of a test and time management during the test. Despite these students receiving SRL interventions outside the classroom, the data that was collected from their classroom setting and specifically using classroom-based, and teacher-made assessments, showing a link to not only SRL strategies and academic achievement but applying it to the classroom context.

Gaps in the Literature

While providing a theoretical backbone for this work, extant literature also illustrates notable gaps that additional research must address. In particular, there is limited literature centering around the explicit links between questions on student SRL development. But there is a logical connection between well-structured tasks, inquiry-based practices, and teacher scaffolds and their effects on self-regulation that can be extrapolated from the literature (Lodewyk et al., 2009; Velayutham & Aldridge, 2013). By bounding a review in the authentic classroom context, we can arrive at novel SRL conclusions in a naturally question-rich setting. While there is literature showing how teacher feedback can directly affect SRL (Hattie & Timperley, 2007), conceptualizing teacher questioning as a form of feedback is a virtually unexplored area of research. Feedback literature makes the claim that feedback should be given and its impact should be measured throughout the lesson rather than just at the end of the lesson or unit (Nicol & Macfarlane-Dick, 2006). Additionally, student-asked questions have the potential power to practice SRL skills (e.g., Chin & Osborne, 2008; Gillies et al., 2012; Hartono, 2013). Given the question-rich, inquiry environment of contemporary science classes, the secondary science classroom context is uniquely situated to provide more insight into these research fields.

The Current Systematic Literature Review

The present study aims to address gaps in the literature by systematically reviewing the intersecting literature of questioning and self-regulated learning in the context of science classrooms. This is an important gap to address, given that both literature bases are vast, and while extant literature shows there could be a relationship, it has not been investigated. The research questions guiding this systematic literature review are grounded in further understanding how questions posed in science classroom contexts affect students' self-regulation. This review of the literature will answer the following questions:

1) How are questions and student self-regulation studied in secondary science classrooms?

2) How are questions and student self-regulated learning related in secondary science classrooms?

When documenting the ways in which questioning and self-regulated learning have been studied, it is important to note certain features: the person or persons of focus; the ways the construct is integrated, documented, and/or measured; and the general design of the study. Each of these can affect the important information that can be gleaned.

Method

Primary empirical studies that involved teachers and students in their 6-12 classroom contexts engaging in questioning and self-regulatory practices were included in this literature review. These studies were found in peer-reviewed journals, excluding textbook chapters and other review articles. This enabled the authors to analyze the primary sources themselves and reduce redundancies. Studies were narrowed down to those only published within the last 20 years to reflect the educational policy changes brought in with the No Child Left Behind Act (NCLB) in 2001. This timeframe also includes the adoption of the Next Generation Science Standards (NGSS Lead States, 2013). Grade levels were also narrowed to ensure more continuity of the science classroom context, as it is operationalized by the researchers. Secondary science classrooms have increased access to laboratory spaces and an increased focus on inquiry process skills in the curriculum (NGSS Lead States, 2013).

Search Criteria

Primary Electronic Search

To identify relevant literature, I adhered to the PRISMA statement (Page et al., 2021) and recent systematic literature methodology papers (Alexander, 2020; Pigot and Polalin, 2020) that outlines how to conduct a systematic literature review, as opposed to a comprehensive review. A systematic, electronic search of the literature base was conducted through the following five databases: ERIC, PsychINFO, Academic Search Complete, Education Research Complete, and Web of Science for peer-reviewed articles published in the past 20 years (2000 to present, 7/1/2020) using sci* AND (ques* NOT "questionnaire") AND (self-reg* OR goal* OR reflect* OR monitor* OR plan* OR control* OR learn* OR reason* OR metacog*) AND class*. A second search was conducted that also included sci* in the title. After all of the duplicates were removed, a total of 848 research papers were included for screening based on our inclusion and exclusion criteria.

Supplemental Electronic Search

In anticipation of the potential implicit nature of studying these constructs and how feedback may play a role, I also conducted a citation search on Butler and Winne's 1995 piece, Feedback and Self-Regulated Learning: A Theoretical Synthesis, in Web of Science, as it is a seminal piece cited across science education, feedback, and SRL literature. Given its large citation count, and our narrowed focus on self-regulation, sci* also had to be in the title and class* in the abstract. This added 73 research papers after duplicates were removed.

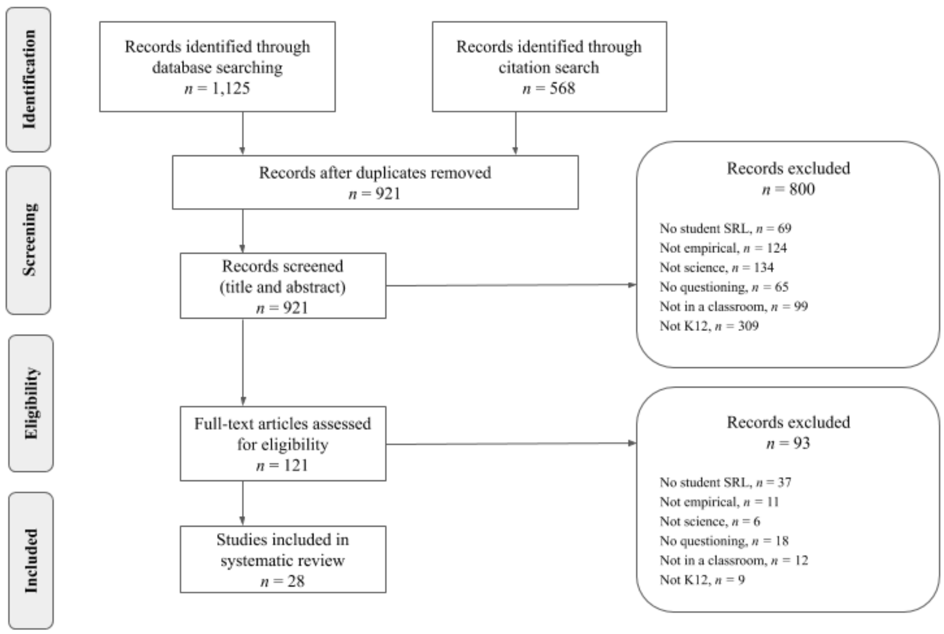
Inclusion Criteria for Abstract and Full-text Screening

I exported the title and abstract of each article into AbstrackR (Wallace et al., 2012). Each abstract was coded, included, excluded, or maybe. This led to 121 articles that possibly met our criteria. Their full citations and articles were exported to excel for further screening.

In addition to applying the above-mentioned criteria, the full-text screening conducted further narrowed the literature to only those meeting the following inclusion criteria: (a) published in an academic peer-reviewed journal and is empirical in nature (including quantitative, qualitative, or mixed methods); (b) written in English; (c) publication date falls between January 2000 and June 2020; (d) examines both questioning and self-regulation among 6th to 12th-grade students. In addition, I only included studies that analyzed student-level self-regulatory outcomes, excluding studies that reported teacher-level outcomes only (e.g., professional development studies reporting on teachers' instruction, McNeill et al., 2016; Authors, 2020); (e) study is conducted in a science classroom. This yielded a total of 28 articles (Figure 1).

Figure 1

Article Screening



Extraction of Relevant Information

The following information from the 28 included articles was extracted, including 1) citation (authors, year of publication), 2) nature of questioning studied, and 3) how questioning is measured, 3) nature of SRL studied, 4) how SRL is measured, and 5) nature of questioning studied, and 5) how questioning is measured (Table 1). The authors then double-coded 20% (*n* = 5) articles, with a 96% interrater reliability, to ensure the information extracted was comprehensive to answer the research questions and completed consistently. Discrepancies were discussed and resolved in weekly meetings.

Table 1

Summary of Questioning and Student SRL

Study	Nature of Questioning Studied	Measure of Questioning	Nature of SRL Studied	Measure of SRL
Adie et al., 2018	Teacher Questions	Class Observations	Metacognitive	Class Observations
Alvi & Gillies, 2015	Student Questions	Class Observations	Cognitive	Student Work and Class Observations
Arvaja et al., 2000	Student Questions in Small Group	Class Observations of Small Groups	Reflection, Planning, Metacognition	Class Observations and Interviews
Cano et al., 2014	Student Trained in Questioning	Class Observations	Cognitive	SPOCK and MAI
Chin & Brown, 2000	Student Questions	Class Observations	Monitor and Reflection	Class Observations
Chusinkunawut et al., 2020	Student Questions in Small Group	Class Observations	Cognitive	Completion of Group Work
Coenders, 2016	Teacher Questions	Class Observations	Planning and Monitoring	Completion of Group Work and Logs
Eggert et al., 2013	Students Trained in Questioning	Class Observations	Cognitive, metacognitive, motivation	Metacognitive Survey
Eilam & Aharon, 2003	Student Questions in Small Groups	Class Observations	Cognitive	Classroom Codes
Eilam & Reiter, 2014	Classroom Questioning	Class Observations	Cognitive	LASSI
Engeness, 2020	Teacher Facilitating Questions	Class Observations	Cognitive	Completion of Group Learning
Gillies et al., 2012	Students Trained in Questions	Class Observations	Metacognitive	Class Observations
Goodnough & Cashion, 2006	Teacher Questions to Scaffold Students	Teacher Artifacts and Interviews	Cognitive	Completion of Project-Based Learning
Hartono, 2013	Student Questions	Completion of 7E Model of Inquiry	Cognitive	Completion of Inquiry Lesson
Jayawardena et al., 2019	Teacher Questions	Class Observations and Interviews	Metacognitive	Class Observations
Lodewyk et al., 2009	Classroom Culture for Questions	Classroom Observations and Interviews	Cognitive, Metacognitive	STPQ and MSLQ
Magaji et al., 2018	Student Questions	Class Observations and Teacher Interviews	Cognitive	Completion of Discourse Activities
Miller et al., 2016	Student Questions	Student Artifacts	Metacognitive	Completion of Warm-up Activities
Nieswandt et al., 2020	Student Questions in Small Groups	Qualitative Class Observation of Small Groups	Cognitive, social, affective	Qualitative Class Observation of Small Groups
Patall et al., 2018	Teacher Reaction to Student Questions	Student Self Report	Motivation	Academic Self-Regulation

				Questionnaire
Radovanovic & Slisko, 2014	Students Asking for Teacher Feedback	Homework Journals	Metacognitive, Cognitive	Homework Journals
Ramnarain, 2011	Teacher Scaffolding to Whole Class	Class Observations	Cognitive	Class Observations
Seeharaj & Samiphak, 2019	Teacher Questioning in Inquiry Setting	Class Observations and Teacher Plans	Reflection	Student Journals
Stott & Hobden, 2019	Student Questions	Class Observations	Cognitive	Completion of Inductive and Deductive Lessons
Velayutham & Aldridge, 2013	Student Questions	WIHIC Questionnaire	Cognitive and Metacognitive	SALES
Wang et al., 2017	Student Questions	Class Observations	Cognitive and Metacognitive	SRQ
Webb-Williams, 2018	Classroom Culture for Questions	Student Artifacts and Teacher and Student Interviews	Cognitive	Student Interviews

Note. 7E Model of Inquiry = Elicit, Engage, Explore, Explain, Elaborate, Extend and Evaluate (Hartono, 2013); WIHIC Questionnaire = What is Happening in Class Questionnaire; SPOCK = Student Perception of Classroom Knowledge; MAI = Metacognitive Awareness Inventory; LASSI = Learning and Study Strategies Inventory; STPQ = Self and Task Perception Questionnaire; MSLQ = Motivated Strategies for Learning Questionnaire; SALES = Students' Adaptive Learning Engagement in Science; SRQ = Self-Regulation Questionnaire

Results

Twenty-eight studies were retained from an international pool of peer-reviewed journals from the last 20 years. They are set in secondary (grades 6-12) science classrooms and study the relationship between questioning and student self-regulated learning. Of the 28 studies, 10 took place in middle school settings (grades 6-8), while 18 took place in high school (grades 9-12). Twenty-two of the 28 studies were conducted outside of the United States, and 23 of the studies were published in the last 10 years. Additionally, a wide range of methodologies was used. Qualitative case studies (n = 12) were the most common, followed by quasi-experimental and mixed methods designs (n = 8). Action research (n = 4) and quantitative studies (n = 3) were also included.

Research Question One: How are questions and student self-regulated learning studied in secondary science classrooms?

The Nature of Classroom Questions and Student Self-Regulated Learning

Questioning Contexts. Well-formulated scientific questions are integral to the construction of new knowledge and student sensemaking. These questions can also be a driving factor in students' self-regulated learning by prompting planning, monitoring, and reflecting. The following section will overview the person or persons of focus in which questioning was studied and documented in studies pertaining to self-regulated learning.

Student Level. Studies that examined questioning at the student level focused on student-generated questions regardless of whom they are directed. General laboratory, cooperative, and inquiry activities that have students work together in small groups were common formats in which student-generated questions were examined (e.g., Gillies et al., 2012; Hartono, 2013; Nieswandt et al., 2020; Radovanovic & Slisko, 2014). Researchers found that students were more accurately completing a challenging homework assignment and accurately reflecting on their metacognitive processing after working in small groups where conversations were rich with student-generated questions (Radovanovic & Slisko, 2014). Additionally, while working in small groups through the 7E Learning Cycle, a structured inquiry lesson pedagogy focused on having the students Elicit, Engage, Explore, Explain, Elaborate, Extend and Evaluate, students were driven by questions throughout the lesson. This resulted in increased cognitive mastery of the topics and critical thinking behaviors (Hartono, 2013). In another small group setting, fine-grain data collection and analysis of student dialogue during laboratory or inquiry assignments was conducted, representing conversations in real-time. Researchers found that students who foster positive, productive lab space do so by asking "insightful [questions] about concepts and procedures" (Nieswandt et al., 2020, p. 277). These three small group settings show how critical student-generated questions can be to learning, even when only studied at one-time point.

Student-generated questions have also been studied longitudinally. During long-term, student-driven, inquiry projects, student group conversations, and the questions driving them, disclosed how students made decisions and progressed towards their goals (Eilam & Aharon, 2003). When given daily and yearly planning guides, students worked together to set reasonable goals and action plans, often asking clarifying and probing questions of the group. Students also leaned on these small groups to manage time and reflect on their progress, asking questions centered around task and strategy-related cues (Eilam & Aharon, 2003). In a similar, longitudinal method, critical thinking, the student questions it manifests, and self-regulation were observed through weekly observations (Wang et al., 2017). Findings showed that over time students' critical thinking and self-regulation increased as they engaged with more socio-scientific issues. In addition, students reported they were asking more questions and generally feeling more comfortable asking questions in front of peers. In a study centered on understanding study autonomy, students were asked about their perceptions on how their teachers encourage, discourage, and react to student questions, quantitatively and qualitatively (Patall et al., 2018). Patall et al. (2018) found that when teachers encourage and engage with students' questions, students feel more engaged, satisfied, and autonomously motivated. It also found the inverse to be true, discouraging student questions had students feeling less engaged, more dissatisfied, and less autonomously motivated. Studying questions in a longitudinal manner yielded a deeper understanding of how students perceive classroom interactions and how it affects their learning and motivation. Different types of learning tasks were also analyzed in the context of student-level questioning. The types of questions students ask during surface and deep approaches led to the recognition of surface (i.e., procedural) and deep (i.e., wonderment) levels of questions (Chin & Brown, 2000). This differentiation of questions was coupled with more elaborate explanations, more cause and effect relationships are identified, and resolving discrepancies in their knowledge. Overall, deeper questions were matched with deeper levels of cognition and metacognition. Cano et al., (2014) specifically trained a subset of students in generating their own questions to a set of scientific investigations. Comparing the two groups, they were able to see that the group trained in asking questions developed more in their self-regulation and had higher academic gains. Lastly, students generated deeper and more critical thinking questions when navigating through "well-structured" or "ill-structured" tasks (Lodewyk et al., 2009). In this study, researchers examined classroom behaviors and student self-report surveys to gain a better understanding of strategies students employ to be successful in different tasks. They found that students ask questions in both ill- and well-structured tasks, but specifically employ more critical thinking in ill-structured tasks, presumably to be able to help themselves navigate the task itself (Lodewyk et al., 2009) These studies looked at student-level questions in differentiated ill- and well-structured settings to look at the different types of levels of questions students would ask. Taken together, questions asked at the student level tend to rely on small group settings, assistance from the teacher when needed, and activities that can structure productive groups.

Teacher Level. At the teacher level, questions were either verbal or incorporated into classwork. Findings showed that teachers' questions served many different purposes. One way teacher questions were integrated into classwork is through the analysis workbook questions and the experimental use of diagrams to help scaffold different levels of questions (Miller et al., 2016). Researchers found that in all questions, students used diagrams more often to help work through difficult level questions and relied more on inferencing (not using the diagrams) on easy level questions. Additionally, preplanned teacher questions were studied to show that they often stimulate the qualities of an inquiring mind (e.g., curiosity, intention, creativity, endeavor, self-study, and reasonableness; Seeharaj & Samiphak, 2019). These preplanned questions also helped scaffold self-reflection, which in turn, helped students be more active in their learning (e.g., asking questions, showing more interest). This shows two ways teacher questions can deepen cognitive and metacognitive thinking.

Teacher questions were also conceptualized as scaffolds in which teachers help students through a task (Engeness, 2020; Ramnarain, 2011). Cognitive questions (e.g., research question probes, how/what/why questions) were asked by the teacher to help small groups of students throughout the inquiry process (Nieswandt et al., 2020). Teachers are also able to provide cognitive and metacognitive scaffolds in the form of guiding questions on lab and inquiry activities which did lead to some students outperforming the control group (Eggert et al., 2013). When explicitly examining teacher questions during planning, conducting, and evaluating and communicating stages of a student task, Ramnarain (2011) found that teachers were very intentional about the questions they asked students at each stage. When planning, they would monitor student groups and intervene with guiding questions to help students clarify and correct their plans or set-ups to ensure the science activity would progress smoothly. During conducting the investigation, teachers would ask questions to check conceptual understandings and assist in students reflecting at the moment to fix problems as they arise. When evaluating and communicating, teachers would ask probing and guiding questions to see any flaws that occurred, think critically about data, and help further understanding.

Lastly, it was shown that questions do not always facilitate student SRL (Eggert et al., 2013; Jayawardena et al., 2019). When these teachers were studied, questions were mostly used to stimulate prior knowledge and in the Initiate-Response-Evaluate (IRE) model. This use of questioning did not support cognitive regulation (Jayawardena et al., 2019). But it was also stated that teachers used modeling, scaffolding, and feedback, which did help students practice their regulation. Additionally, an experimental group of students who received metacognitive question training did not always outperform the control group (Eggert et al., 2013). These confounding results, led the researchers to think that students may not have used them to their full potential. In addition, they believed that reflection questions were rushed at the end of class and often fell short of their intended purpose. In summary, there is strong evidence to show how teacher questions can impact student SRL, while being room to explore some unexpected results from some studies. This calls for explicit further analysis on whether teacher questions do and do not enhance student SRL would help these mixed findings, through studies explicit exploring this relationship.

Both student- and teacher-generated questions. Studies that examined questioning from both teachers and students focused on didactic dialogue patterns between teachers and students and often the questions that drive that dialogue. These confounding results, led the researchers to think that students may not have used them to their full potential. In addition, they believed that reflection questions were rushed at the end of class and often fell short of their intended purpose. Arvaja and colleagues (2000) focused both on the depth of student questions as well as the initial question given by the teacher. They found that student questions focused on just answering the teachers' questions with facts were shallower and less generative than deeper student questions that focused on reasoning. Additionally, students were also interviewed and asked about how they perceived the social-cognitive environment their teacher established. Goodnough and Cashion (2006) conducted an in-depth case study of one teacher through project-based learning and collaborative inquiry lessons. They concluded that when the teacher acted as a facilitator for learning, she asked more questions to individual students, did more listening, and let students drive more of the learning. This more student driven culture is highlighted further with the fact that students were given the space to ask more of their own questions that drove the project-based and collaborative lessons. Findings showed that teacher questions influence the way students think through and complete tasks. A question-rich classroom environment, in which all persons feel they can be involved, is important for generating deep thinking.

Working Definitions of Self-Regulation. Zimmerman's model of self-regulated learning (2002) The most common way self-regulation was defined by the studies was with the work of Zimmerman. His framework was cited in 13 out of the 28 studies. Zimmerman focuses on the cognitive and metacognitive conditions in which students self-regulate in the classroom. These studies recognize the steps of planning, monitoring, and reflecting as crucial elements of students' self-regulating their learning (e.g., Cano et al., 2014; Eilam & Reiter, 2014; Wang et al., 2017).

One study recognized the crucial elements of cognitive SRL but also placed a heavy emphasis on the effort and behavioral aspects of SRL. It specifically connected those aspects of the learning environment (e.g., involvement, investigation, cooperation, equity) and motivational constructs (e.g., task value, learning goals, and self-efficacy; Velayutham & Aldridge, 2013). Additionally, Engeness (2020) added a social emphasis to the traditional three-phase cognitive model, underscoring the importance for teachers to share the agency of learning with students. They found that teachers help orient students to all of the appropriate resources available to them and monitor their progress through the learning task when circulating the classroom.

Alvi and Gillies (2015) identify the importance of individual cognitive self-regulated learning but then extend to discuss how those impact student motivational constructs of self-efficacy and outcome expectations. Pintrich and Zusho's (2007) served as a framework for Jayawardena and colleagues (2019). This model of motivation and SRL look at how personal characteristics (e.g., age, gender) and classroom contexts (e.g., academic tasks, instructor behavior, instructional methods) affect motivational (e.g., efficacy, values) and regulatory (e.g., regulating cognition, motivation/affect, behavior, and context) processes. The model also shows how motivational and regulatory processes affect each other and outcomes (e.g., choice, effort, achievement).

Student SRL was also studied implicitly in several studies. Seven studies use general metacognition (e.g., Chin and Brown, 2000), motivation (e.g., Eggert et al., 2013), or aspects of self-regulated learning as their framework. These studies examined students as they think critically and reflect on their learning or task-level outcomes, without formally defining SRL (e.g., Gillies et al., 2012). Arvaja et al. (2000) recognized that critical thinking and problem solving require planning, reflection, and metacognition. Others rely solely on student reflection as a mechanism for increased critical thinking (Seeharaj & Samiphak, 2019). In regards to motivation, Patall et al. (2018) used motivation, engagement, and self-determination theory as the basis for their study on student autonomy. They found that when students were more agentic in the learning process, their motivation and engagement increased.

Measurement of Questioning and Student Self-Regulated Learning in the Classroom

Classroom Questioning Measurements. The next section provides a synthesis of the different ways questioning was documented in science classrooms. Most of the questioning measures were qualitative in nature.

*Coding Classroom Observations***.** Several different coding schemes of teacher and/or student questions appear in the data. One coding scheme incorporated the quality of dialogue and the type of task they were completing (Arvaja et al., 2000). They coded dialogue into "uncritical knowledge sharing" or "critical knowledge building", noting that critical reasoning/knowledge building was a prerequisite to cooperative learning. Uncritical knowledge sharing utilized mostly "what" questions that supported surface-level understanding, not deep reasoning. Critical knowledge building was evidence of high-level cooperative learning, engaging students deeply, and includes the use of timely teacher scaffolding (Arvaja et al., 2000). Student questioning behaviors were also coded for alongside interacting behaviors, helping behaviors, and problem-solving behaviors. Questioning behaviors were specified to be "asks questions to stimulate, clarify or recall the discussion, elicit factual information or promote thinking" (Gillies et al., 2012, p. 98). This was supplemented by analyzing teacher mediating behaviors, categorized into basic and extended mediation. Basic mediation includes "asking questions that require minimal responses" and "open-questions" (Gillies et al., 2012, p. 99) while extended mediation included probing ideas, asking for clarification and expansions, and "providing indirect help by asking a sequence of questions designed to help student consolidate their understanding" (Gillies et al., 2012, p. 99). Through these layers of coding, it was determined that extended and swift mediation of teachers provides scaffolds to student learning and development.

When focusing on teacher questioning, one strategy was to use broad codes of teacher questioning in planning, conducting, and evaluating to see emergent themes in helping facilitate student learning throughout science investigations (Ramnarain, 2011). Teacher questions were also coded in three ways (prompting students' self-correction, related to emotions/motivation, or prompting students' self-regulation; Adie et al., 2018). These codes were used in conjunction with other codes to specifically identify the purpose of every utterance by students and teachers. After the fine-grain coding, frequency tables were made and broad themes were identified (Adie et al., 2018). Lastly, teacher questions were noted in classroom transcripts and a pattern emerged; the focus teacher would ask a series of questions that promoted student self-regulation and complex thinking and evaluative skills (Alvi & Gillies, 2015).

Coding student questioning was the most prevalent in the literature in regards to student self-regulation. One trend between the coding schemes and purposes of the study was the reliance on co-constructing knowledge with peers or the ability to navigate through a task on a more individual level. When monitoring student small group behavior, and how effective those groups can be, researchers coded three levels of student questions "learning about content," "understanding group member's view," or "confirming group member's explanations" (Nieswandt et al., 2020). These were never analyzed on the individual student level, rather, kept on the group level to inform teachers and researchers of the holistic characteristics of student groups. Additionally, when working in small groups, students' own questions, along with their judgments and reasoning seem to have helped exhibit their critical thinking and self-directed learning (Stott & Hobden, 2019).

At the individual student level, all student discourse was coded when working in small groups through warm-up questions; the coding scheme for this study did not identify questions specifically, rather they were embedded in the following codes: making inferences, metacognitive monitoring, off-task behavior, and disagreements (Miller et al., 2016). More directly focused on questions, broad codes noting student ways of thinking and scientific discourse were applied to classroom transcripts, and then inductive categories showed differences between surface and deep approaches to science activities (Chin & Brown, 2000).

One emergent theme was that surface approaches utilized more factual and procedural questions while deep approaches used more questions to reflect curiosity, processing, puzzlement, and wonderment. Most interestingly for this review, it was also noted that deep approaches also had students self-questioning to maintain SRL throughout the learning activity (Chin & Brown, 2000). Overall, coding schemes are a powerful tool for analyzing classroom dialogue and can be done successfully in a variety of ways to meet the needs of the study.

Other Qualitative Approaches. When not studied through coding schemes, some studies made conclusions about questioning because of how present they were in the classroom through other qualitative means. They arrive at their conclusions after seeing how teachers and/or students use questioning in the classroom. When studying the ways to make project-based learning more effective for K-12 students, researchers noted that pre-planned questions written in lesson plans and on the spot scaffolding questions during class helped students through this novel science pedagogy (Goodnough & Cashion, 2006). In student-centered inductive science lessons, students generate their own conclusions from many examples, increasing the cognitive load on students, when compared to teacher-directed, deductive science lessons. Teacher questions posed quickly became a hallmark finding, with results showing that questions helped students with the increased cognitive load of inductive lessons. In addition, these questions helped facilitate productive conversations in which students were able to have deeper thoughts around the content (Stott & Hobden, 2019). Also impacting students' cognitive load, well and ill-structured tasks had students employing a variety of problem-solving techniques (Lodewyk et al., 2009). Among these problem-solving techniques were students' ability to answer questions on the activity by the teacher and asking to help guide them through the tasks. Specifically, it was shown that students ask a variety of lower and higher-order questions on both ill and well-structured tasks, but the structure of the task does have effects on motivation and cognition. For example, when working on a more cognitively demanding, well-structured task, students need to ask more high-order questions to be successful (Lodewyk et al., 2009). While studying how to enhance students' critical thinking in class, questions became important to help students learn from one another in a laboratory setting (Hartono, 2013). This was also a resulting theme when students worked through phases of homework. When progressing from individual, group, and back to individual homework, it was evident that students learned from one another by asking and answering higher-order questions (Radovanovic & Slisko, 2014).

Lastly, several studies' questions were integrated by explicit teacher choices. Students were guided through research, concluding, and problem questions on their lab worksheets as a cognitive scaffold during group work (Nieswandt et al., 2020). Students were also prompted to ask questions on a log that was answered by their teacher. This increased, quicker feedback helped students' self-efficacy and motivation (Coenders, 2016). Then, teachers also asked students metacognitive questions and saw mixed results in improving students' self-regulation and decision making while dealing with socioscientific issues (Eggert et al., 2013; Jayawardena et al., 2019). Additionally, structured journal prompts (e.g., "where", "why", "how" questions) supported students' curiosity and intention, both connected to self-regulation (Seeharaj & Samiphak, 2019). Lastly, small group inquiry activities, with student-generated questions at the heart of the activities, drove a study investigating student critical thinking and self-regulation (Wang et al., 2017). Qualitative observations of the classroom, even in the absence of a coding scheme, can yield important understandings about the function and benefits to questions in the science classroom.

Self-Report Measures. Student self-report measures (e.g., interviews, diaries, surveys) help to capture how students perceive the classroom questioning environment. Daily diaries centering around classroom aspects that help or hinder student autonomy revealed that how teachers respond to student questions is related to their autonomy, self-efficacy, and motivation (Patall et al., 2018). Those students who felt their teacher encouraged their questions or did not shut them down felt more motivated and autonomous (Patall et al., 2018). Students also took the "What is Happening In This Class" survey to show connections between how classrooms function and students' self-efficacy, motivation, and self-regulation (Velayutham & Aldridge, 2013). This self-report survey showed that students believe that engaging with peers and more constructivist activities, all done through more questioning, would increase their self-efficacy, motivation, and self-regulation (Velayutham & Aldridge, 2013). Lastly, through interview data, students reported that increased verbal feedback, including in the form of questions, was helpful for their learning (Webb-Williams, 2018), specifically in helping them become more independent learners. While self-report measures rely on the recall skills of the students, it also provides a unique insight into their perceptions and other thoughts students may have that are not detectable in observations.

Shared Experimental Resources. In some studies, questions were integrated into the methods of the study, resulting in training led by a research team or common classroom protocols. Studies either set up activities that encouraged student questions (Chusinkunawut et al., 2020; Eilam & Aharon, 2003), trained students in different questioning techniques (Cano et al., 2014; Magaji et al., 2018), or had the teachers facilitate using their own questions or prompts (Coenders, 2016; Eggert et al., 2013). Inquiry projects naturally are going to have students enhance their questioning in the classroom. Several research teams looked at student outcomes when inquiry practices were used more often in the classroom. Through independent, longitudinal student projects, it was shown that students will facilitate each other through questions to help guide them to complete their projects (Eilam & Aharon, 2003). Also working in the collaborative, inquiry setting, student questions were noted to help them negotiate, discuss, evaluate, and argue in order to complete the activity (Chusinkunawut et al., 2020). This shows how students will navigate through small-group inquiry projects.

In two studies students received explicit instruction training on cognitive and metacognitive questions. In one of them, students were trained in Bloom's levels of questions in the hopes of enriching their level of discourse (Magaji et al., 2018). Results revealed that students were more engaged, which they measured through their questioning and feedback, level of clarity, how they probed and analyzed others' points of view, and successfully problem-solved. In a second study, when trained in metacognitive questions, students used those questions to see significant gains in self-regulatory skills (Cano et al., 2014). These questioning interventions deepened student learning.

Student Self-Regulated Learning Measures. The included studies utilized a range of methodologies to measure and analyze student self-regulated learning in secondary science classrooms.

Quantitative Measures. Quantitative measures were commonly used when studying SRL in the classroom. These measures were exclusively student-self-reports including academic self-regulation questionnaire (Patall et al., 2018), SALES (Students' Adaptive Learning Engagement in Science) (Velayutham & Aldridge, 2013), LASSI/WSRI/YSRI/TSRI (Eilam & Reiter, 2014), SRQ (Chinese version) Wang et al., 2017), cognitive and metacognitive survey (Eggert et al., 2013), SPOCK/MAI (Cano et al., 2014), STPQ/MSLQ (Lodewyk et al., 2009). No quantitative measure was used in more than one study.

The review of the most prevalent measures used in the SRL literature shows that there are a variety of ways SRL can be conceptualized and measured. The Motivated Strategies for Learning Questionnaire (MSLQ) has two sections separating out motivation and learning strategy scales (Lodewyk et al., 2009). The Self and Task Perception Questionnaire (STPQ) has a motivational focus with strong ties to the motivational theory of Expectancy Task Value (EVT) (Lodewyk et al., 2009). Lastly, the Learning and Strategies Study Inventory (LASSI) has three scales (skill, will, and self-regulation), with subscales accounting for emotions, research management, information processing, and motivation (Eilam & Reiter, 2014).

Semi-Structured Interviews. One qualitative measure of students' SRL is a semi-structured interview protocol. The interview was a component of mixed-methods and multi-methods studies. In a convergent mixed-methods design, student interviews showed how social-cognitive behaviors in the classroom help students' self-efficacy in science classrooms (Webb-Williams, 2018). The interviews revealed that verbal teacher feedback while students are "planning, checking, and goal-setting" made them feel more confident (Webb-Williams, 2018, p. 953). In another study, teacher interview data was analyzed after classroom observations. Teachers were asked directly about how they support students' SRL development in which they replied how they scaffolded and created activities to help students plan, monitor, and reflect on their learning (Jayawardena et al., 2019). While semi-structured interviews were never the sole measure, they provide valuable insights into student perceptions of their learning.

Work Samples. In one study, homework samples were also coded for SRL. In Radovanovic & Slisko (2014), self-reflection questions were asked after students completed homework individually, and then with their groups. These self-reflection questions were coded by researchers who were looking for important SRL behaviors such as expressing doubts and concerns and asking for feedback from peers and/or their teacher. These work samples provided a way for students to demonstrate their thinking and reasoning in real-time.

Classroom Observations. Another source of real-time student data was classroom observations. Classroom observation data was coded for SRL behaviors exhibited by students in several different ways. Some isolated only student behaviors within small student groups (e.g., Nieswandt et al., 2020; Eilam & Aharon, 2003) while others looked at interactions between students and teachers (e.g., Adie et al., 2018; Alvi & Gillies, 2015). Adie et al. (2018) coded teacher actions and student reactions when talking to each other in class. They had teacher codes such as “goal setting”, “specific strategy for improvement”, and “asking questions to prompt student self-regulation” and student response codes (e.g., “negotiate”, “challenge”, “respond with a question”. After using these and other codes, the team concluded that when feedback opened dialogue and allowed students to reflect, student self-regulation was developed further. This was often, but not always, in the form of questions from the teacher. Researchers concluded that this differentiated coding of teacher and student was vital to analyzing student-teacher interactions.

Student-focused behavioral coding schemes varied. Affective, social, and cognitive engagement verbal and physical actions were coded while students worked in small groups to determine the co-regulatory success of the group to complete an inquiry task (Nieswandt et al., 2020). Students needed to exhibit positive behaviors in all of these aspects in order to be the most productive. Additionally, student behaviors such as being interactive, questioning, helping, and problem-solving were also coded as indicators that students were using higher-order reasoning and cooperative inquiry skills (Gillies et al., 2012). These skills are indicators of observable self-regulated learning that students would exhibit. These give insight into how researchers can code for student SRL when focusing on different facets.

From a metacognitive perspective, directly coding for self-monitoring and self-reflection during surface and deep levels of science approaches also informed researchers on the self-regulatory habits of students (Chin & Brown, 2000). This direct coding scheme was conducted on a small number of students that the researchers specifically chose for their approaches to learning science (surface or deep). It revealed that when deep learning approaches are employed in the classroom, students will exhibit more self-monitoring and self-reflection behaviors. Lastly, Eilam and Aharon (2003) developed these eight codes for student SRL: considering alternatives, monitoring and reflecting, increased awareness of cues over monitoring, readjusting plans, planning habits, accountability, looking further ahead, and manipulating plans. This direct coding scheme was used on a small subset of the sample, some high-achieving students and some low-achieving students.

A combination of interviews and classroom video data that focused on the facilitation of small group student investigations through teacher questions found that teachers intentionally use questions to help scaffold and support student thinking while working through investigations (Ramnarain, 2011). It is important for the teacher to intervene throughout the investigation to ensure the investigation is set up and conducted properly and analyzed critically. Intervening with questions allowed teachers to redirect without directly telling the students what to do, which helps students develop more reflection skills. "It is envisaged that when learners become used to reviewing their work, they will not require someone else to help them reflect on what they did, but will do so spontaneously" (Ramnarain, 2011, p. 99). They make the explicit distinction that these types of questions, those that "[encourages] learners to articulate, reflect on, clarify and review their thinking and actions” rather than “closed questions” that are present in a “teacher-controlled” environment (Ramnarain, 2011, p. 100), foster autonomy in students throughout scientific investigations.

Inductive coding was also employed with classroom observation data. One study focused on dialogue patterns between students and teachers, taking note of the types of feedback and questions being asked, inductively generating the resulting self-regulatory skills and strategies (Adie et al., 2018). Also, Alvi and Gillies (2015) took “scenes” that were transcribed verbatim from the classroom and reflected on the teacher's purpose and student regulatory outcome during each talk-turn. In addition to their semi-structured interviews, Jayawardena et al. (2019) also observed classes for teacher and student interactions. They coded interactions broadly at first and then in the second round of coding fit interactions into the Pintrich and Zusho (2007) motivation and SRL framework. Engeness (2020) saw how teachers help facilitate student learning by helping them orient to a science task and monitor their progress by asking guiding questions to small groups of students. In the absence of deductive coding, these findings show that when making classroom observations, student SRL manifestations are apparent.

Ability to Complete Individual or Group Tasks. Finally, in the remaining studies, student SRL is assumed given that students were able to complete their tasks. Journals and logs used as part of the methodology, designed to help students plan, monitor, and reflect, were completed by students without descriptive or differentiating analysis (e.g., Arvaja et al., 2000; Goodnough & Cashion, 2006). These direct interventions did show greater critical thinking and successful collaboration skills. Additionally, critical thinking, inquiry, and laboratory activities were used in methodologies that require students to regulate in order to complete (e.g., Patall et al., 2018; Chusinkunawut et al., 2020). While not interventions, they were part of the methodology, being outlined in the instruction styles of the teacher. All students in these studies had to regulate in order to complete these tasks. This product-focused view of student SRL is important since student productivity and agency are important goals in education.

Summary of Student Self-Regulated Learning

Of the included studies the vast majority were guided by a social cognitive framework. Within this framework though, conceptual frameworks and operationalized definitions of self-regulated learning varied. While a group of studies relied on the cognitive phases of planning, monitoring, and reflecting presented by Zimmerman, a large percentage of studies also focus on behavioral and emotional aspects, while some others more generally discuss metacognition. This variety of working definitions of self-regulated learning is reflected in the wide variety of measurements and methodologies used since the studies have varying purposes. It is noteworthy that over three-quarters of the studies at least had some component of qualitative data collection and analysis, which is more uncommon in the SRL literature base (Zimmerman, 2013). Some larger themes taken from these studies show the connection between teacher structured learning environments, which includes an environment rich with questions, discussions, and discovery, and motivation and self-regulation. One study found that all motivational constructs significantly predict students' self-regulation, as well as student cohesiveness, task orientation, and investigation. This shows a logical flow of how learning environments can influence student motivation, and both will influence self-regulation (Velayutham & Aldridge, 2013).

Research Question Two: How is Questioning and Student Self-Regulated Learning Related in Secondary Science Classrooms?

To address the second research question, I synthesized findings regarding the relationship between classroom-based questions and student self-regulated learning. Three major trends emerged that (1) showed that questions were utilized to either assess where students were in their self-regulation development, (2) helped serve as a scaffold to help students through regulation, and (3) helped support in their practice of regulation.

Trend 1: Student Questions Reveal Their Self-Regulated Learning

Several studies revealed that the types of questions students ask reveals their present level of SRL. In the reviewed studies, researchers used a variety of strategies to determine student SRL levels from classroom questions. These ways include inductively by researchers (e.g., Goodnough & Cashion, 2006), using qualitative coding schemes (e.g., Nieswandt et al., 2020), a quantitative measure (Lodewyk et al., 2009), or a combination of those (e.g., Chusinkunawut et al., 2020).

When analyzing how students cognitively, socially, and affectively regulated to create productive inquiry in small group spaces, Nieswandt and colleagues (2020) showed that all student interactions in small groups, including the questions they ask one another, can show how successfully the students are co-regulating within an activity. Researchers took note of how students were asking clarifying and guiding questions to their groups, which demonstrate cognitive and progress monitoring. Also in the small group setting, the depth of the questions students ask is related to their cognition and metacognition (Arvaja et a., 2000). Those students asking shallower questions focus on lower levels of cognition (e.g., recall) and exhibit less metacognition (e.g., reflection) while deeper questions probe at higher levels of cognition (e.g., reasoning) and more metacognition (e.g., processing).

In inquiry lessons, student questions can reveal their current level of thinking and regulation. “Critical thinking can be seen in the learners’ judgments, supported by reasons, and their use of questions to self-direct learning.” (Stott & Hobden, 2019, p. 37) Additionally, when students are asking questions to guide them self in an inquiry activity, they are demonstrating their self-regulated learning. In a study designed to show the effectiveness of a design-based inquiry approach, DBSP+, student-driven questions inspired whole inquiry lessons and researchers found that these questions could not only drive exploration but also argumentation and problem solving (Chusinkunawut et al., 2020), all of which require self-regulation. Taken together it shows that questions can be used to help researchers and teachers discern student SRL.

Trend 2: Teacher Questions Scaffold Student Self-Regulated Learning

Questions asked by the teacher were analyzed by how they scaffolded students to become more self-regulated (e.g., Alvi & Gillies, 2015). These scaffolds were often in the form of probing questions which "encouraged them to form evaluative judgments and make metacognitive actions to regulate their thinking" (Alvi & Gillies, 2015, p. 23) This scaffolding behavior was observed directly (e.g., Eilam & Rieter, 2014; Engeness, 2020) and reflected on by teachers (e.g., Goodnough & Cashion, 2006). In an experimental study designed to explicitly show the benefits of direct SRL interventions in the classroom, researchers found that in order to create a classroom space for students to practice SRL behaviors, teachers needed to provide constant encouragement and support (Eilam & Rieter, 2014). It also was shown to be verbal (e.g., Adie et al., 2018) and embedded into worksheets and other assignments (e.g., Chusinkunawut et al., 2020). In a quasi-experimental study with metacognitive conditions, metacognitive guidance questions were supplied to teachers to help students work through the socioscientific issues in small groups (Eggert et al., 2013). These studies show how questions help students practice or get to a higher level of self-regulation.

Ramnarain (2011) highlights that probing and guiding questions serve as intervening scaffolds to students during scientific investigations. They distinguish that these questions are not closed and teacher-controlled, but are helping the students reflect and help solve their own problems. This is hypothesized to aid in student autonomy and regulation skills. Adie et al. (2018) found that when teachers provided dialogically engaging feedback in the form of questions, students are able to "[develop] as self-assessors who are active agents, self-regulating their learning" (p. 721). These studies show the impact that teacher questions can have on student SRL.

Trend 3: Student Questions Support Their Self-Regulation

Student questions also support their own SRL. When students worked in small groups on homework problems, the questions they were able to ask each other were noted as particularly helpful for understanding and monitoring their progress when reflecting in the self-regulation part of the homework (Radovanovic & Slisko, 2014). In a study incorporating more socioscientific issues into classroom discourse spaces, these types of conversations fostered more questions and supported students' critical thinking and SRL (Wang et al., 2017). Another way to foster more meaningful SRL in students was by encouraging deeper questions (Chin & Brown, 2000). When working in small groups on year-long projects, the questions students asked each other were shown to help with control, monitoring, reflection, task and strategy use, and controlling their environment (Eilam & Aharon, 2003). When students were specifically trained in scientific and metacognitive questions, they showed both academic and SRL gains (Cano et al., 2014). It was even noted that self-questioning by students was a particularly helpful tool in fostering more SRL. Lastly, in a quasi-experimental design, there were no significant SRL differences between student groups engaging in cooperative activities versus inquiry activities

(Gillies et al., 2012). However, the authors interpreted the lack of SRL differences based on the student-initiated, question-rich environment across both sets of activities.

Discussion

The results of this systematic literature review explore how SRL and questioning have been conceptualized and documented in empirical research, as well as the relationship between questioning and self-regulated learning in science classrooms. From the presented studies, evidence of student SRL, when not measured by self-report, is largely product-focused. These products could be the successful completion of a lab activity (e.g., Goodnough & Cashion, 2006), critical thinking or inquiry work (e.g., Hartono, 2013), or how they respond to questions raised by their classmates or teacher (e.g., Alvi & Gillies, 2015). This product-focused nature of measuring SRL is helpful for assessing where the students are in regards to their regulatory skills but could fail to show any co-regulation occurring, by which students work together to influence each other's regulation (Hadwin et al., 2018), or any individual-level reasoning taking place during the process. Given that regulation is a cyclical process (Zimmerman, 2002), to more accurately represent SRL in the classroom, real-time processing should be measured.

Findings from this systematic review also showed that the relationship between questioning and SRL can be reciprocal or bidirectional. For example, it was evident that teacher questions helped scaffold students' SRL (e.g., Jayawardena et al., 2019) and peer questions helped students regulate and co-regulate (e.g., Nieswandt et al., 2020). It was also shown that students' self-regulation played a part in what types of questions they would ask. When students were asking higher-order questions in inquiry activities, they were able to practice their regulatory skills. These questions were often asked to peers, which could aid in others' regulatory skills as well.

Focusing on contextual feedback in the classroom, these studies help show the natural use of questions to drive classroom inquiry can provide levels of feedback to the students and teacher. When teachers use questions to scaffold, this provides feedback that the student can use to guide their learning and regulation. Additionally, when students ask questions, this gives an indication of their level of understanding and regulation, providing their teachers with feedback.

Lastly, and most notably, the results of this systematic review show that student SRL and classroom questions were not both isolated as foci of any empirical study. When SRL was empirically explored in the classroom setting, questions, along with other dialogic components, were noted as contributing factors (e.g., Alvi & Gillies, 2015; Eilam & Reiter, 2014). This is when researchers were studying factors that impacted student SRL, classroom questions were often reported as impacting student metacognition, achievement and SRL. Conversely, those studies that focused on classroom questions noted student SRL along with other motivation and academic factors (e.g., Cano et al., 2014; Ramnarain, 2011). Lastly, there were studies that noted questions and SRL in the larger scheme of how social cognitive, dialogic factors contribute to academics or motivation (e.g., Eggert et al., 2013; Nieswandt et al., 2020). All of these studies bring to light the relationship between questions and student SRL. However, no study explicitly examined that relationship as the sole focus of the study.

Contributions of the Systematic Review

This systematic review helps contribute to the literature and to classroom practice. It helps organize and summarize two broad and entangled literature bases and pieces together connections that could not have been made otherwise. By documenting the intersectionality of classroom questions and student self-regulation in science classrooms, novel conclusions can be made that would not be otherwise possible. For example, it is impactful to discuss how several studies noted how teacher questions can scaffold student SRL and how several studies all arrived at this conclusion independent of one another.

With the variety of definitions and focuses of the studies, combing through and interpreting explicit and implicit connections helped shed light on new findings. This also begins to point researchers to new ways to study questioning and SRL. The range of methodologies, frameworks, and purposes outlined in this review can help researchers frame and execute new studies. For example, studying student SRL through more qualitative means can help researchers understand the nuances of student metacognition. Popular qualitative measures such as classroom observations and student diaries/logs could be employed more by future researchers. Additionally, the frameworks used in studies could be expanded given the variety of types of student SRL seen in this review. For example, if SRL was only implicitly studied under a larger metacognitive frame, it can be molded into a study to explicitly study SRL with the help of another study reported in this review. Lastly, this review truly sheds light on the importance of studying educational constructs in authentic classroom settings. Social-cognitivist mechanics are at work in many different ways in a classroom, all happening at the same time. If researchers have focused research questions and a logical and thorough way to capture and analyze classroom dynamics, we can begin to understand how students progress in the context they learn.

Implications for practice also arise from this review. Training for in-service and pre-service teachers on purposeful and deep levels of questioning is important. This was demonstrated in several studies showing how teacher questions have an impact on student SRL. Additionally, teachers also should create an atmosphere in their classroom where students feel safe and confident to ask questions in order to progress their learning. This review revealed that student questions can help teachers assess their regulation and can help support their regulation.

Limitations of the Systematic Review

This review has limitations. While the narrowed focus on secondary science classrooms was justified and purposeful, more could be gained by looking into elementary science classrooms as well. The practices around questioning and relationship with SRL could help show how students begin early on with these constructs. In addition, other secondary classrooms that use similar question-rich environments (e.g., social studies, math, English language arts) could provide cross-curricular insight into the development of SRL through questions. Also, the basis of this study is focused on cognitive and metacognitive self-regulated learning. Broadening the working definition of SRL to include behavioral and emotional components, would show more of the multidimensional nature of SRL and potentially how they all interplay in the classroom context. Building strong student-teacher relationships and an inclusive classroom environment could be analyzed by viewing more of the behavioral and emotional viewpoints. Lastly, 6th grade to 12th grade is a wide lens from a developmental perspective. Considering SRL is affected throughout development, delving deeper into those developmental time points and their impact on the SRL seen in classrooms would be beneficial.

Future Research

This review, and the analysis completed within it, explored the ways that questions in the classroom and student self-regulation are related to one another. This work can be advanced with the following calls for future research.

Taking Advantage of the Authentic Science Classroom Context

This work could benefit from studies conducted without interventions or experimental groups (Gillies et al., 2012). Several quasi-experimental design studies concluded this from their inconclusive results (e.g., Gillies et al., 2012; Wang et al., 2017). This led researchers to hypothesize the natural inquiry space most likely has a strong mediating effect. Questioning and self-regulation could be studied by simply looking at scientific inquiry spaces as they naturally exist with the students and teachers.

This new approach to SRL research would also recognize the important general classroom factors that Dignath and Veenman (2021) describe as "powerful learning environments." In addition to teaching SRL skills explicitly, this idea states that teachers can foster SRL skills in their students without teacher SRL strategies explicitly (e.g., teaching students how to reflect in a journal log) or implicitly (e.g., giving students access to a reflection log without instruction on how to use it or requiring its use). Classroom questioning could be very well situated in fostering student SRL via "powerful learning environments" which can consist of cooperative learning and opportunities for student choice.

Further quantitative and qualitative work could analyze how questions in the classroom align with the qualities of a powerful learning environment. This data should be collected in real-time and analyze the ways in which SRL is developed and supported in the classroom.

Being Intentional in Researching the Relationship Between Questions and Student Self-Regulated Learning

Additionally, since many conclusions were derived from indirect conclusions from the included studies (e.g., Nieswandt et al., 2020), meaning researchers did not intend to look for a relationship between questions and SRL. Therefore, more studies need to be conducted that explicitly address the relationship between questions in the classroom and student SRL. This means developing research questions and methodologies to specifically measure and analyze the relationship between questions and SRL.

Since questions are such a high-yield pedagogical tool, research can focus solely on this aspect of the classroom and how it drives students to be more self-sufficient learners. Question research in science classrooms is already prevalent, but they focus largely on academic outcomes (e.g., Chin & Osborne, 2008; Manz & Ranga, 2017). By focusing on SRL as an outcome, we can further understand the benefits of a question-rich classroom. A mix of qualitative and quantitative measures would need to be employed to capture and measure important dialogic components of the authentic classroom and how they relate to students' SRL.

Measuring the Process Rather than Simply the Product

Self-regulated learning is a process to help understand how and why a person thinks and behaves as they do as they make their way to a goal. Several studies recognize the importance of achieving learning goals and analyze SRL in terms of the degree to which students were successful in achieving the goal (e.g., Eggert et al., 2013). While they took observations or notes about the process, the focus was still largely on the product (e.g., lab report, project). Further understanding of how the classroom environment supports student SRL could be achieved by also measuring the process students take in reaching a goal. These probes could be in the form of students journaling their process, metacognitive reflection questions at the end of an assignment, or teachers probing for students' thinking throughout the activity. This would more accurately probe for important SRL facets such as environmental regulation, monitoring, resource management, help-seeking, etc. It would be important for quantitative and qualitative work to be done to assess the frequency, quality, and nature of SRL behaviors students exhibit through the learning activity.

Going Beyond Self-Regulation to Recognize Other Agents in the Process

Helping students become independent learners is important, highlighting the importance of self-regulation. However, coregulation (the transactional process in which members of a community work towards a common goal) and socially shared regulation (members of a group regulating together towards a common goal) also take place in the classroom and should be researched further in the classroom context (Hadwin & Oshige, 2011). The classroom is not an island where students learn in isolation. They are interacting with their teacher and peers. Therefore, coregulation and socially shared regulation are skills students should also learn. Only one study in this review mentions the presence of socially shared regulation and its vitality for the group for completing its shared goal (Nieswandt et al., 2020). Further, these forms of regulation also can play an important role in scaffolding students to become more self-regulated (Azevedo & Hadwin, 2005). But these forms of regulation have almost exclusively been studied through virtual platforms, not inside of authentic classroom spaces (Winne, 2010). More can be understood about regulation, its development, and how it relates to motivational and academic outcomes by researching in classroom spaces. Video and audio observations of the classroom, as well as student reflections on their perception of these interactions with others, would give insight into how students are learning with and from others.

New Measures for SRL

In order for the previously suggested work to happen, we need to create and validate more qualitative measures for studying SRL in the classroom. This would most likely look like researcher rubrics, coding schemes, and analysis of student work and classroom discourse. First, a distinct set of observable student actions should be compiled of a variety of SRL dimensions. It is important to recognize that while so much of student SRL is internal, there are observable manifestations that teachers and researchers can be trained to recognize. Once validated, SRL training for teachers, administrators, and qualitative researchers could more easily happen. For teachers, professional development on common regulatory behaviors would help them target on-the-spot interventions needed to help students progress during that class period. Over time, they could also notice behavioral changes in their students, indicating increased self-regulation. Administrators could be trained in what to look for during classroom observations to expand discussions with the teachers beyond academic and classroom management progress but to include motivational progress as well. Lastly, researchers would have a tool to use during in-person and classroom observation. This would help advance the qualitative work of the SRL field, which has been a limitation noted in the literature (e.g., Cleary & Zimmerman, 2012; Perry, 2002).

Conclusion

Students learn and grow within their classroom spaces. Beyond academic measures, it is important to understand the ways in which they grow as independent learners. This will have longitudinal effects on their academic performance and motivation. Given that questions are so prevalent in a science classroom, this is an important area to focus on when looking at how the classroom context affects students' SRL.

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Self- and Socially-Regulated Learning in Middle School Science Classrooms: A Multiple Case Study

Abstract

Students must employ self-regulated learning (SRL) and socially-regulated learning (soRL) in the science classroom, which includes a wide array of independent and collaborative learning activities. However, little is known about how student SRL and soRL co-occur in students' learning and how the classroom teacher influences that regulation in situ (Cabrera et al., in preparation; Panadero et al., 2015). This explanatory, sequential case study analyzes classroom video data from six middle school science classrooms. The study uses an integrated coding scheme that captures SRL and soRL behaviors, soRL modes, and targets of regulation (Greene & Azevedo, 2009; Hadwin et al., 2018; Heirwig et al., 2019; and Zimmerman, 2002). Results show that student SRL and soRL behaviors are influenced by the activity structure and physical layout of the classroom, regulatory behaviors mostly manifest as behavioral and cognitive regulation in the performance phase, and teachers impact student regulation by prompting behavioral monitoring and comprehension monitoring. Theoretical and practical implications are discussed in addition to future directions for SRL and soRL research.

Keywords: Self-regulated learning, socially regulated learning, science, middle school

Self- and Socially-Regulated Learning in Middle School Science Classrooms: A Multiple Case Study

Regulation, or the effort and awareness of one's actions, thoughts, emotions, and motivations towards a goal, is an important 21st-century skill (Jarvenoja et al., 2015). Regulation is required when a deadline is imminent (e.g., planning what needs to get done to get a paper turned in on time), when frustrations occur in the workplace (e.g., working through personal setbacks to keep your productivity up), and juggling multiple tasks (e.g., prioritizing and working through email, presentations, and analyzes all one day). Regulation is clearly needed in the workforce, and it is also integral for students to be successful in the classroom. The classroom setting presents a variety of tasks (e.g., worksheets, research projects, experiments) and multiple formats (e.g., individual, small groups, whole class) in which students need to successfully complete complex learning activities (Schunk, 2005). For example, students must keep track of assignments and plan how to complete them on time. This involves setting short-term and long-term goals, monitoring their progress, assessing if they are completing the assignment accurately, and seeking assistance when they need it. There is empirical evidence that strong regulatory skills lead to higher academic achievement (e.g., grades) and motivation (e.g., interest and perceptions of competence; Cleary & Kitsantas, 2017; Dent & Koenka, 2016; Eilam et al., 2009).

One way students must regulate in classrooms on the individual level, or self-regulate. Students' self-regulated learning (SRL) encompasses various facets of students' behavior, emotions, motivation, and cognition (Pintrich, 2000). *Self-regulated learning* (SRL) is an

> active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior

in the service of those goals, guided and constrained by both personal characteristics and the contextual features in the environment (Pintrich, 2000, p. 453).

This definition highlights all of the ways a student can self-regulate their learning and the influence of interpersonal and intrapersonal factors. At the heart of SRL research is the pedagogical goal to support students in increasingly taking ownership of their learning process, thus increasing their academic independence. Additionally, self-regulatory processes in the classroom are often impacted by the teacher and peers. Self-regulated learning can be viewed through a social-cognitive perspective (e.g., Zimmerman, 2013; Hoyle & Dent, 2018). Social-cognitive theory explains how human interactions can support individuals' learning, motivation, and regulation (Schunk and Usher, 2019). That is, self-regulation of learning is developed through an iterative process of interactions with other people, such as teachers and peers, and students' interpretation and understanding of these interactions in relation to their own thoughts and motivations. Students will often learn self-regulatory behaviors from others or be prompted in ways to be more self-regulated (Hoyle & Dent, 2018; Jarvenoja et al., 2015). Looking beyond the individual student level, peers can also be tasked to work together in groups towards a common goal, which can only be achieved by regulating and working together as a group. Lastly, the teacher is often supporting a student's regulation by monitoring (e.g., prompting students to follow directions) and helping their students (e.g., providing scaffolds to guide their thinking) as they work in individual and group settings.

More specifically, science classrooms demand unique regulatory skills for students. Student self-regulated learning (SRL) is uniquely supported by the modeling and teaching of scientific inquiry (Greene et al., 2018). While engaging in scientific inquiry, students undergo the stages of SRL: planning, monitoring, and reflecting (DiBenedetto, 2018). Planning is mirrored in designing procedures for conducting systematic investigations. For example, when students are designing a scientific experiment, they have to be descriptive and intentional in their plans, or procedures, they develop. Monitoring one's actions during an investigation (which includes controlling one's actions and adjusting to fix any problems that arise) are practiced by carrying out the procedures they developed, such as data collection and analysis procedures. Students will have to monitor to make sure they are conducting the investigation correctly, and adjust their behaviors if necessary. Students reflect when analyzing and interpreting their data, presenting their findings, considering limitations, and developing the next steps for their work. Taken together, the processes of scientific inquiry lend themselves well to the development of students' SRL skills.

On a group level, the nature of science requires the co-construction of knowledge, which can only be achieved in classrooms when students engage in collaboration, discourse, and inquiry together. (Bae et al., 2021; Jarvenoja et al., 2015; Miller et al., 2018; Stroupe, 2014). Extant literature shows these social elements of the classroom learning environment are also crucial for student engagement, interest, and persistence in science (Bae & Lai, 2020; Lemke, 1990, 2004; Murphy et al., 2018; Ryu & Lombardi, 2015). Recent science education reforms (National K-12 Framework for Science Education; National Research Council [NRC], 2012) also highlight the importance of social ways of learning. For example, the Next Generation Science Standards (NGSS) science practices outline disciplinary ways of knowing and communicating where students and teachers work together to co-construct understandings (e.g., asking questions, constructing scientific explanations, planning and carrying out investigations; NGSS Lead States, 2013).

To make these social modes of learning (e.g., collaborative group projects and labs) meaningful and productive, students need to exhibit strong social regulation skills (Panadero & Jarvela, 2015). Social regulation refers to a group being in control of their actions while working towards a common goal (Hadwin et al., 2018). In the science classroom context, planning and carrying out science experiments involves several social regulation skills. For example, ensuring the group is following the directions requires the group to monitor their progress (e.g., taking observations, keeping time) and adjust parts of the protocol as unexpected problems arise during an experiment. As another example, when engaging in a productive small group or whole-class discussions centered around socioscientific issues, students must stay on topic (e.g., listen and respond to ideas around a common topic) and monitor their emotions (e.g., refrain from negatively reacting when frustrated; Sadler, 2011). It is important to also recognize the sociocultural climate of the classroom, given the amount of interactions present and the diversity of the classroom. Given that urban classrooms are characterized by diverse cultural practices, social and economic dynamics, and racial/ethnic diversity, studying social interactions and regulation in these spaces is a rich context. Thus, this study is positioned to highlight the opportunities for students to regulate in classrooms that represent spaces of both inequality and possibility (Green 2015; Warren & Chambers, 2020).

Middle school science classrooms also present unique characteristics. Middle school science teachers are likely to be content area specialists, with degrees in the sciences, whereas elementary teachers often do not have this specialty (Appleton, 2006). This teacher specialization can be associated with science classrooms operating more like real-world science laboratories, which require collaboration. However, from a developmental standpoint, middle school students are still developing the regulatory skills in order to work together productively in collaborative science classrooms (Cleary & Chen, 2009). Therefore, the middle school science teacher is uniquely positioned to support the development of co-regulated learning within their classrooms (DiBenedetto, 2018).

Given the dynamic and complex nature of social learning in middle school science classrooms, the role of the teacher as a facilitator to support productive learning is crucial (Dignath & Veenman, 2020). Empirical evidence shows that high-quality pedagogy that supports regulation (e.g., planning and supporting student-driven lessons) is positively associated with student discourse in the classroom, co-construction of knowledge, and completion of group tasks (Smart & Marshall, 2013). Studies also show that teacher choices, actions, and interactions, such as offering choices, providing scaffolds, opportunities for self and peer evaluations, and non-threatening, mastery-oriented teacher feedback, help student metacognition and self-regulation (Perry et al., 2002). To date, most of these studies focus on interventions with students, such as teaching metacognitive skills directly (e.g., lessons on how to take better notes, Eggert et al., 2013; Eilam & Reiter, 2014; Gillies et al., 2012). There is a lack of studies that have examined SRL as it occurs in real-time within classroom contexts, although some more recent studies have begun to examine the nature of SRL in situ (Dignath & Veenman, 2020; Perry et al., 2002, 2020). For example, Perry and colleagues (2002) examined teacher pedagogical moves in relation to student self-regulated learning in elementary classrooms. Findings showed that classrooms in which teachers promoted SRL development typically had the following pedagogical strategies as indicators: offered student choices, gave students opportunities for self-control, self-evaluation, and peer-evaluation, gave support to students from the teacher, and peers, and gave evaluation in a non-threatening and mastery-oriented manner. However, Perry et al. (2002) only focused solely on individual students' self-regulated learning.

There is room to expand on this work by examining the impact of teacher pedagogical moves on student social regulation. This study aims to better understand social regulation by examining the ways in which teachers interact with their students in science classrooms. By looking at the ways teachers interact with their students in social learning spaces, we can better understand how students are socially regulating, and the actions teachers are taking to improve students' regulatory skills in situ.

Review of the Literature

Given the variety of terms and multiple perspectives of regulated learning in the literature, the following section will define and distinguish self-regulated learning (SRL) and socially regulated learning (soRL). Regulated learning broadly describes an active, controlled means of accomplishing a learning goal (Jarvenoja et al., 2015). The interpersonal context in which learning goals are being completed serves to differentiate self-regulated learning (SRL; Zimmerman, 2000) and social regulation of learning (soRL; Hadwin et al., 2018). Table 1 further distinguishes three modes of regulation within soRL and SRL.

Table 1

Overview of Self and Social Regulated Learning

Regulated Learning- to be in control of one's thoughts and actions while working towards a learning goal (Jarvenoja et al., 2015)			
Interpersonal context	Regulating in the presence and interacting with others on group goals or tasks- **Social Regulation of Learning (soRL;** Hadwin et al., 2018**)**		**Self-Regulated Learning (SRL)**- Individuals own use of learning strategies, response to feedback, and fostering motivation within a classroom (Zimmerman, 2000)
Modes of Regulation	**Socially Shared Regulated Learning (SSRL)**- when the group of students is regulating their group's behavior to reach their learning goal (Hadwin et al., 2018)	**Co-Regulation of Learning (coRL)**- the stimulation of regulatory behaviors in which one person will modify, redirect, or prompt another person resulting in a shift or internalization of regulatory processes (Hadwin et al., 2005; Hadwin et al., 2018)	**Self-Regulated Learning (SRL)**- individuals own thoughts and behaviors as they work towards their goals within a classroom (Dragnic-Cindric & Greene., 2021)

To be able to distinguish between self-regulated learning literature and socially regulated learning literature, I will first focus on the theoretical background of self-regulated learning, it's expansion to socially regulated learning, socially regulated learning modes, the perspectives from which they have been studied, and the empirical evidence that informs the present study. Gaps in the extant literature, such as the lack of empirical studies in middle school science classrooms, and our proposed study for addressing them are also discussed.

Self-Regulated Learning

To understand how individuals self-regulate their learning, scholars have broken down what and how students regulate. According to Hoyle and Dent (2018), self-regulated learning can be broadly categorized as either external (e.g., help seeking behaviors) and internal (e.g., information processing) resource management. A more fine-grain view describes SRL by what the student is regulating, or their targets or regulation (Dragnic Cindric & Greene, 2021; Greene, 2018). Six targets of SRL have been identified: 1) emotions (e.g., moods and reactions), 2) behaviors (e.g., actions), 3) cognition (e.g., study skills), 4) metacognition (e.g., allocating time and prioritizing), 5) motivation (e.g., setting goals), and 6) metamotivation (e.g., awareness of what motivates one's self, Dragnic Cindric & Greene, 2021; Greene, 2018; Miele & Scholer, 2017).

SRL has been studied through various perspectives that differ in emphasis of focal constructs (e.g., cognitive, motivational, behavioral, environmental/contextual, and affective/emotional). It has traditionally been examined within a cognitive perspective, focused on how students process information. The study of student self-regulation also has a long tradition in motivation research, which focuses on more affective experiences such as students' interest, self-efficacy, and persistence in a task. Additionally, within developmental psychology, self-regulated learning can be viewed as a skill that becomes more sophisticated over the course of a student's schooling.

From a cognitive perspective, SRL is studied through learning strategies employed by students with the purpose of better understanding and retaining the content (Panadero, 2017). This perspective often looks at data probing for specific student learning strategies such as highlighting, summarizing, and making study guides. From a metacognitive perspective, researchers focus on students' processing and organizational skills centered around how they learn (e.g., setting goals and planning for them; Pintrich, 2000). On the metacognitive level, goal setting, planning, self-monitoring, self-control, and self-evaluation behaviors are the focus. This connects to the three stages of a widely used framework of Self-Regulated Learning outlined by

Zimmerman (2002): 1) Planning, 2) Monitoring, 3) Evaluating. Through these stages, students progress through learning activities to achieve their learning goals.

From a motivational perspective, SRL centers what drives students to independently move through learning tasks (Zimmerman, 1989). As stated by Wolters (2003), motivational SRL can be understood as the deliberate use of one's motivation to complete learning activities by means of specific strategies such as the increasing task value, self-consequating, or mastery self-talk. Studies have shown that SRL is highly correlated with self-efficacy, task value, and mastery-oriented learning approaches (Daumiller & Dresel, 2019; Lim & Yeo, 2021; Pintrich, 1999).

From a behavioral perspective, SRL focuses on how students regulate their actions with the purpose of engaging in on-task learning behaviors such as following deadlines and directions (Hoyle & Dent, 2018). Environmental regulation (also referred to as contextual factors by Pintrich [2000]) focuses on how students attempt to control their surroundings to maximize their learning (e.g., time maintenance, quiet workspace). Lastly, emotional or affective regulation addresses students' feelings as influential factors in the learning process (e.g., anxiety, excitement, interest; Boekaert, 1996).

It is noteworthy to mention that while these cognitive, motivational, and behavioral perspectives can be examined in isolation, both leading and more contemporary SRL frameworks take multiple perspectives into account (Boekaert, 2011; Miele & Scholer, 2018; Panadero, 2017). For example, Pintrich and Zimmerman's frameworks focus on motivational factors of SRL, but also highlight cognitive and metacognitive factors. Boekaert's (2011) Dual Processing model emphasizes emotional, or well-being, factors of SRL and how they interact with cognitive, or mastery/growth, factors (Panadero, 2017). More specifically, self-regulation can have multiple purposes, which can interact with one another. The well-being pathway helps students maintain safe and reasonable boundaries, with their behaviors and emotions, while the mastery/growth pathway aims to expand knowledge and skills. Boekaert (2011) recognizes that the mastery pathway acts in a "top-down" fashion and the well-being pathway acts in a "bottom-up" fashion. Importantly, internal (e.g., self-talk) or external (e.g., teachers and peers) can stimulate a shift between these two pathways. The recognition of the multidimensionality of SRL supports the call for research in SRL that applies qualitative methods to better understand SRL in specific contexts, and the integration of multiple frameworks for a more complete representation of student SRL (Perry et al., 2002; Schunk & Zimmerman, 2011).

Methods Used to Examine Self-Regulated Learning

Studying student SRL is largely done through self-report measures, trace measures, and think aloud protocols which attempt, but do not always succeed, to capture the complex and dynamic ways SRL can be expressed (Boekaerts & Corno, 2005; Cleary & Zimmerman, 2012; Zimmerman, 2008). Individual self-report measures that ask students to rate how their SRL development and skills are progressing (Dinsmore et al., 2008). A recent systematic literature review of SRL in secondary science classrooms showed that self-report surveys, such as the Learning and Strategies Study Inventory (LASSI, Weinstein et al., 2016) and the Motivated Strategies for Learning Questionnaire (MSLQ, Pintrich et al., 1991), are the most common measures of SRL (Cabrera et al., in preparation). These measures ask students to remember, reflect, and self-judge their own regulation and are useful for being able to capture the retrospective and internal facets of SRL, but lack the ability to capture these SRL events objectively as they occur in real-time (Cleary & Zimmerman, 2012).

Researchers also developed trace measures analyses and think-aloud protocols (TAP) for examining SRL. These methodologies are helpful for identifying objective and observable indicators in real-time. Trace measures rely on coding video and audio data with a list of indicators of SRL (Cleary & Zimmerman, 2012). TAP elicits student verbalization to attempt to capture overt (externally visible) and covert (purely internal) manifestations of SRL (Greene & Azevedo, 2009). TAP for SRL often uses computer programming or researchers working directly with students to prompt students to verbalize their thoughts and record the dialogue for coding.

Coding Self-Regulated Learning Data

In this section, I review coding schemes for trace measures and TAPs. The coding scheme for this study drew on these presented codebooks. One of the codebooks, presented by Greene and Azevedo (2009), used 35 SRL micro-level indicators that incorporate five processes of SRL. These indicators were divided into five macro-level processes of SRL: planning, monitoring, strategy use, task difficulty and demands, and interest. This coding scheme was applied to recordings of middle and high school science students as they went through a self-paced, computer module about the circulatory system to find predictor variables and developmental trends in mental mapping of the circulatory system. Greene and Azevedo (2009) used both micro (short actions) and macro (longer episodes) level codes to understand how students were self-regulating as they developed an understanding of complex science concepts.

Another TAP analysis scheme organized SRL into three phases aligned with Zimmerman's (2002) cyclical model of SRL: the forethought and planning phase, the performance phase, and the reflection phase (Heirweg et al., 2019). Similar to the scheme by Greene and Azevedo (2009), it has micro-level subcategories that specify finite regulatory actions. Heirweg et al., 2019 used their TAP analysis with fifth and sixth graders in Belgium in conjunction with quantitative data from the Children's Perceived use of Self-Regulated Learning

Inventory (CP-SRLI, Vandevelde et al., 2013) to create four student SRL profiles. The TAP analysis provided information to run cluster analyses on emergent patterns of student SRL behaviors. Other SRL codes have been presented in relation to specific SRL frameworks. Zimmerman (1989) provides a table of 14 SRL strategies that he delineates to support the idea of the triadic SRL model, which is heavily tied to social-cognitive theory. The triads are the person/self, their environment, and their behavior. He postulates the student can regulate themselves internally, regulate their environment, and regulate their behavior using one or more of the 14 strategies (e.g., self-evaluation, goal setting and planning, organizing and transforming). In an updated paper, he presents his three-phase model of SRL, including forethought, performance, and reflection. He supports the model with component SRL skills that students can use a mix of such as effective time use, adapting, and choosing appropriate strategies (Zimmerman, 2002). Lastly, Pintrich (2004) also supports the use of multiple SRL strategies throughout the stages of the learning activity. While developing the MSLQ, he identifies important times when a student can apply several SRL strategies, such as restructuring their environment, setting goals, and evaluating their own motivations.

When the analysis schemes are examined together, some important overlaps emerge. First, it is important to consider multiple dimensions of SRL (e.g., motivation, cognition, behavior) as students can tap into several dimensions throughout a learning activity. Second, it is important to have more indicators rather than fewer, due to the variety of ways students may choose to exhibit their regulation. To best represent the regulation occurring in the classroom, a range of fine and coarse grain coding is necessary to comprehensively capture SRL in classrooms Greene (2013). Therefore, Greene (2013) proposed quantifying and reporting codes on both levels and aggregating codes together when it aligns with the learning gains and predictors the study is focused on. Lastly, regulation can look differently during unique points of the learning activity (before, during, and after). Thus, it is important to capture and interpret SRL behaviors in relation to the context of the learning activity in which they take place. The creation of the coding scheme and analysis used in this study addressed these recommendations and gaps in the literature by creating a comprehensive codebook, aimed at capturing all targets of regulation (e.g., motivation, cognition, behavior, affect) and examining regulation on the coarse and fine grain size, to accurately represent regulatory episodes in the classroom.

Self-Regulation Research as the Basis for Social Regulation Research

Social regulation research, which began to emerge in the late 1990s, uses the knowledge established by SRL as a foundation (Hadwin et al., 2018). Social regulation recognizes ways individuals can regulate (e.g., their behaviors, thought processes, environment), but builds onto them by examining how those individuals regulate in groups, working on group goals. Also, when making the shift to understanding social regulation, scholars recognize that the interactive cycle of forethought, performance, and reflection can take place within a group setting. Groups also have internal (e.g., cognitive, motivational, metacognitive) and external (e.g., physical environment) factors to regulate (Hadwin et al., 2018).

There are a variety of regulatory demands placed on students in a classroom and many ways scholars have attempted to understand their regulation. As a student is working through activities in the classroom, they can be exhibiting and processing within and between all of these individual to more social aspects of SRL (e.g., emotional reactions can cause a student to freeze up during a learning activity, causing them to either shut down and not ask for help or reach out for peer or teacher assistance). Given the variety of ways students regulate themselves in the classroom, multiple SRL and social regulation frameworks will be applied to guide the present study. Each of these are reviewed next.

Social Regulation Modes (i.e., self-, co-, and shared- regulation)

Self-regulated learning (SRL) refers to the ways an individual student moves towards their own learning goals, whereas social regulation of learning (soRL) refers to how multiple individuals work towards shared learning goals in a social setting (Dragnic-Cindric & Greene, 2021). Due to the inherently social nature of student-driven inquiry, discourse, and co-construction of knowledge in science classrooms, students in science classes are often working together to complete assignments and come to a group understanding of concepts (Rogat et al., 2019). For example, often an experiment will require two or more students to set up and run the experiment and the analysis and conclusions are enriched by that student group discussing their results and reasoning together. As students engage in these social learning activities, they will employ a variety of regulatory modes (Dragnic-Cindric & Greene, 2021): self-regulated learning (SRL), co-regulated learning (coRL), and/or socially shared regulated learning (SSRL). The literature for social regulation of learning (soRL) is rooted in the long-standing literature base of self-regulated learning (SRL; Hadwin et al., 2018). Table 2 overviews the commonalities and differences between regulatory modes that fall under social regulatory processes (Dragnic-Cindric & Greene, 2021; Hadwin & Oshige, 2011).

Table 2

Social Regulation Modes

Social Regulation Mode	Who is regulating?	Goal of Regulation	Language Indicators	Facet of Regulation (What are they regulating?)	Regulatory Process
Self-Regulated Learning	Individual Student	Their own actions for their own learning goal	"I need/will/have to… for my/our…"		
Co-Regulation of Learning	Individual Student	Another's actions for a common goal	"You should/need to… for our/your…"	Cognitive, metacognitive, behavioral, emotional, motivational, environmental	Forethought, Performance, Reflection
Socially Shared Regulation of Learning	Pair or group of students	The group's actions for their common goal	"We should/will… for our…"		

Self-Regulated Learning in Group Settings

Self-regulated learning (SRL) research that falls under social regulation, although traditionally focused on an individual's regulatory processes, also accounts for the influence of environmental influences on these individual processes by drawing on social-cognitive and sociocultural theory (Panadero & Jarvela, 2015). Zimmerman's social cognitive model of self-regulation (1989) explains that SRL is shaped by our social context and environment. SRL is also framed within Vygotsky's (1978) sociocultural framework that allows researchers to explain and understand the ways in which SRL can be supported through feedback, modeling, and scaffolding. This extends the traditional view of SRL as an individual's own thoughts and behaviors as they work towards their goals by accounting for the presence of others (Dragnic-Cindric & Greene, 2021).

Contemporary social regulation research also recognizes that any given student's SRL can influence events in which social regulation is occurring (Hadwin et al., 2018). For example, if a student is exhibiting strong SRL behaviors (e.g., setting goals, assigning roles, keeping time), in group settings, they can use their SRL skills to help drive the group forward towards their goal. SRL behavior in social settings is typically highlighted with the phrases “I am” or “I will” recognizing that one student is aware of the plan and taking action towards the goal (Dragnic-Cindric & Greene, 2021). In the classroom, that often looks like one student working in a group working on the assignment by themselves and then catching the group up if they fall behind or if groups split up the work between members to “divide and conquer”. Conversely, if a student is exhibiting poor SRL behaviors (e.g., not recognizing deadlines, having off-task conversations), they may actively be hindering their group’s progress. Overall, research shows that when there are strong SRL skills amongst individual group members, the group is more likely to work collaboratively in a productive fashion (Hadwin et al., 2018).

Co-Regulation of Learning

Co-regulated learning (coRL) refers to regulatory behaviors in which one person will modify, redirect, or prompt another person to regulate (e.g., follow directions, set a goal, keep time). These prompts must result in a shift or internalization of regulatory processes of the recipient receiving the SRL feedback (Hadwin et al., 2005; Hadwin et al., 2018). An important feature of coRL is the clear imbalance of the use and quality of regulatory skills, wherein some students are displaying more or stronger skills and are attempting to shift the skills of other students displaying less or weaker skills (Panadero & Jarvela, 2015). For example, co-regulatory behavior is typically highlighted with the phrases “you should” or “you need to” implying that one student is guiding the other towards more positive regulatory actions (Dragnic-Cindric & Greene, 2021). It is thought that this shift or internalization in turn allows the other student to exhibit better regulatory skills in the future, showing that not only does co-regulation help during the current learning activity but in future activities as well (Hadwin & Oshige, 2011). While coRL often can have the outcome of improving the way the group moves towards their learning goal, its purpose is to improve an individual's regulatory behavior within the group setting.

Notably research shows that it is important to have the right environment for coRL to take place. Bakhtiar et al. (2018) looked at how the climate of the classroom affects student co-regulation. Without proper incoming conditions, student coRL cannot occur. Specifically, emotional coRL was found to be important during forethought (i.e., planning), negative emotions constrain coRL, and encouragement and motivating comments help coRL.

Socially Shared Regulation of Learning

Socially shared regulated learning (SSRL), in contrast to co-regulation, refers to when the group of students is regulating their group's behavior to reach their learning goal (Hadwin et al., 2018). In these social settings, the group is balanced in their display and use of regulatory skills (Panadero & Jarvela, 2015). SSRL is characterized by multiple people in the group expressing agency through the fluid flow of ideas and metacognitive strategies. This behavior is typically highlighted with "we" or "us" phrases, instead of the "you" statements of co-regulation or "I" statements on self-regulation (Dragnic-Cindric & Greene, 2021).

Strong SSRL skills have been shown to increase group performance (e.g., task completion, grades; Panadero & Jarvela, 2015). When students in a group are working together to complete a task, the task is more likely to get completed at a higher quality if group members exhibit strong regulatory strategies (e.g., keeping time, asking clarifying questions, checking to make sure answers are of high quality). This can also be seen in the motivational and emotional targets of regulation (e.g., Jarvela & Jarvenoja, 2011; Rogat & Linnenbrink-Garcia, 2011; Volet et al., 2009). When group members have positive interactions (e.g., neutral or positive tone of voice, coming to consensus) with one another, they remain emotionally balanced (i.e., happy or even tempered) and motivated. This in turn helps to keep the whole group on track.

The Sociocognitive, Sociocultural, and Situative Perspectives to Social Regulation

Based on the premise that social regulation is interpersonal in nature, Jarvenoja et al. (2015) and Volet et al. (2009) outline three main perspectives that have emerged in the literature to contextualize social regulation: sociocognitive, sociocultural, and situative. The sociocognitive perspective places an emphasis on effective individual regulation in order for the group to succeed as a whole, deriving from a person-in context perspective (Pintrich, 2000). This perspective aims to understand how the self-regulation of individuals affects the group (Jarvenoja et al., 2015). Further, the sociocognitive perspective acknowledges the mediating role of self-regulation social regulation, stating that the more self-regulated an individual is, the more likely the social regulation in their group will be effective (e.g., McCaslin, 2009; Volet et al., 2009). In contrast, the sociocultural perspective emphasizes the intersubjectivity and interpersonal interactions within a socially constructed setting, such as a classroom (Jarvenoja et al., 2015; Volet et al., 2009). For example, sociocultural research may focus on the type and features of the environment students are working in, and its potential effects on groups' learning processes (Jarvenoja et al., 2015).

Lastly, the situative perspective takes a middle stance, recognizing that within productive social learning, both individual and interpersonal factors are present and interacting. The situative perspective of regulation acknowledges that all individuals are regulating themselves within the group setting as well as working together as a group towards a collective goal (Jarvenoja et al., 2015). Because this perspective accounts for both individual and group regulation, the situative perspective of regulation serves as the theoretical perspective of this study.

Key Findings Regarding Student Social Regulation of Learning in the Classroom

While limited, the emerging social regulation literature provides some empirical foundation for future work. In a review of soRL, Panadero and Jarvela (2015) analyzed 13 empirical studies to conclude the distinguishing factors between the three modes of soRL, socially shared regulation, co-regulation, and self-regulation. Findings showed that all of the studies involved qualitative data analysis, usually in the form of video observations ($n = 11$). Mixed methods were the dominant research design, with no experimental or quasi-experimental designs present.

In a case study conducted by Ucan and Webb (2015), the emergence and functions of coRL and SSRL were explored in a middle school science classroom as they studied body systems. They examined how student groups navigated small group science activities through metacognitive, emotional, and motivation lenses. Findings showed that metacognitive coRL emerges when individuals in the group can identify and verbalize their misunderstanding. Additionally, metacognitive SSRL occurs when group members discuss moments of disagreement and work together towards a consensus. Lastly, emotional and motivational SSRL was displayed when the group failed to reach consensus, a member was disruptive during the activity, and/or when group members had different priorities during the activity. Ucan and Webb (2015) rarely mention teacher interactions in their summary and transcriptions. However, in their discussion, they recognize the potential impact the classroom teacher had on student group work. In their discussion, they attribute the evidence of positive coRL and SSRL to student-teacher interactions before and during the small group activity including providing written instructions for the activity, verbalizing explicit group norms for collaboration, monitoring all groups, and checking in with groups to assist or provide positive feedback on their progress or behavior. The value in exploring this gap in the literature regarding the teacher's role in students' SSRL processes is stated (Ucan & Webb, 2015). The present study aims to address this gap by exploring how the teacher stimulates students' regulatory behaviors.

Teachers' Influence on Student Regulatory Behaviors

In a study focused on the teacher's role in promoting student SRL, Perry and colleagues (2002) used a case study design to identify five distinct actions teachers can take to help their students self-regulate in second and third grade classrooms during teacher-planned reading and writing activities. They found student SRL was stimulated when teachers offered a variety of choices within the lesson or activity (e.g., flexible seating and choice of learning strategy), opportunities to control their level of challenge, opportunities to reflect on their own work, and provided feedback to peers. Teachers also promoted SRL by providing instrumental support (e.g., asking students a guiding question to help the student choose the correct strategy rather than just prompting them with the correct thing to do) and providing mastery-oriented (i.e., focused on one's own understanding of the content), non-threatening feedback. These strategies were either pre-planned for the lesson or provided on the fly. While not situated in middle school science classes, this work established the idea that everyday teacher choices can and are affecting student SRL.

In another study, Perry et al. (2020) worked with classroom teachers to show how assessments and feedback foster student SRL during writing tasks, in third grade classrooms. They documented student SRL levels in each classroom and labeled each classroom as a "high SRL class" or "low SRL class." High-SRL classes and low-SRL classes were compared across the following three factors: descriptions on how the classroom promoted student SRL, student self-assessments, and student writing samples from an assignment co-constructed by the teacher and researchers. They found that in high-SRL classrooms, teachers communicated clearer instructions and expectations, designed activities with larger goals that incorporated more student choice, provided more scaffolding questions to guide student progress, and generally gave more metacognitive, as opposed to procedural feedback. These classrooms also involved more student co-regulation.

Lobczowski et al. (2020) examined social regulation in relation to science discourse, stating that science is an inherently "social endeavor". They used a coding scheme that included deductive codes for soRL mode (i.e., SRL, coRL, SSRL, External), socioemotional characteristics (i.e., positive and negative), and discourse elements (i.e., questions and responses). These discourse elements included micro codes for types of questions (i.e., authentic or test, and teacher or student initiated). The research team also conducted open, inductive coding. They found that both the teacher and student leaders both can emerge to initiate social regulation. Specifically, teachers intervened when the content was particularly challenging. They systematically documented the shift in student regulation after teacher interventions, showing the affects teachers can have on student regulation in science classrooms.

Quackenbush and Bol (2020) examined how teachers support co- and socially shared-regulation in middle school math classes. They found that teachers most often help with the performance phases of regulation followed by forethought and reflection respectively. Teachers supported student regulation by circulating during activities, checking in with students, and specifically asking guiding and probing questions.

Rationale for the Study

Currently, emerging literature is beginning to explore how regulation occurs within classroom settings. This study added to this by examining these interactions specifically in middle school science classrooms by focusing on the everyday interactions students and teachers have, such as asking probing questions, prompting student redirections, and checking in with individuals and student groups.

The field of self-regulated learning often relies on intervention-driven or quasi-experimental methods (Cabrera et al., in preparation) in which novel instruction techniques and lessons are implemented in secondary science classrooms. Examples from contemporary studies include: asking students metacognitive questions in inquiry settings (Gillies et al., 2012), teaching regulatory skills directly (Wang et al., 2017), and giving more unstructured opportunities for student inquiry (Ramnarain, 2011). In several of these studies (e.g., Gillies et al., 2012; Wang et al., 2017), the authors concluded that an area of future research could be investigating the choices and actions teachers make in absence of interventions. Even after deliberate regulatory training was delivered to groups of students, researchers saw that significant gains were also made within the control group, leading researchers to consider that in the typical science classroom setting, student regulation is supported through learning activities that inherently require and foster regulatory skills. This study aims to target a crucial gap in the literature, one which takes advantage of the natural pedagogical moves teachers make to ensure individual students and groups of students self-regulate productively in class.

Another gap in the literature to address surrounds methodological choices such as the setting, research design, and analytic tools used to study self- and social-regulation. The science classroom is a rich setting to better understand self-regulation, but it has not been explored fully in the literature to date. Findings from contemporary studies show that regulation is dependent on contextual factors such as proximity to a teacher (Dragnic-Cindric & Greene, 2021), the variability in learning activities (Moos & Ringdal, 2012), and the opportunities for choice, reflection, and non-threatening feedback in the lesson (Perry et al., 2002; 2020). The science classroom is a complex context that consists of interpersonal factors (e.g., frequent collaboration with other students, the teacher) and discipline-specific factors (e.g., experiments, lab equipment). In addition to the need for self-regulated learning research within real-time classroom contexts, there is a need to understand how student regulation manifests in domain-specific ways as afforded by science classroom environments. Finally, social regulation in science classrooms needs further focus. This will allow a better understanding of ways that science classroom lessons often incorporate social learning (e.g., small-group laboratory work, student-driven inquiry lessons, classroom discussions centered on socioscientific issues; Bae et al., 2020; Sadler, 2004).

Qualitative approaches (e.g., video observations, think-aloud protocols, and trace measures) provide real-time, contextualized data on student regulatory behaviors in complex education settings (Perry et al., 2002). These qualitative tools present valuable affordances to better understand student regulation in context and the ways teachers can help support students' regulation in the moment. However, to date student regulation is primarily measured through student self-report surveys (e.g. LASSI, MSRQ; Cleary & Zimmerman, 2012) which rely on accurate student self-awareness and self-reflection. These quantitative measures typically do not account for the contextual factors that impact a students' regulation and treat regulation as a finite, individual trait rather than a dynamic skill that can be employed differently given the specific context. Greene (2021) modeled theoretically how student metacognition and SRL are supported by their teacher. His prototypical model summarized how teacher direct and indirect self-regulated teaching (SRT) helped support student metacognitive and cognitive development. SRT is affected by a host of factors including professional view, teachers' own SRL, beliefs, and knowledge of SRL. Greene (2021) states there is a need for methodologies to capture the changing and cyclical nature of student SRL and the ways it is impacted by the classroom teacher.

This study addresses this gap by accounting for the natural science classroom context with regard to student self- and socially regulated learning. Social regulation in authentic classroom contexts includes accounting for teacher pedagogical choices in designing the classroom space and lesson, as well as student-teacher interactions, such as teacher prompting and scaffolding. To date, these have not been studied (Panadero & Jarvela, 2015; Ucan & Webb, 2015). This line of inquiry is important to better understand the ways in which student regulation manifests in their classrooms and how teachers can support and foster these important regulatory practices in science.

The middle school classroom also is an underexplored context for regulation research. Of the 13 studies in the meta-analysis by Panadero and Jarvela (2015), five were conducted in elementary schools and six in higher education, leaving only one study focusing on middle school students (grades 6-8) and one study on secondary students (grades 6-12; Grau & Whitebread, 2012). Middle school is an important stage of students' academic journey. It is a time in development that is characterized by an increased capacity for abstract thinking, planning, reflection, and collaboration (Wigfield et al., 2005). Socially, it is also a unique time that students increasingly rely on their peers and non-familial adults. This makes middle school a prime, and understudied, time to study social regulation, given that middle school students are apt to seek validation from peers and teachers and have an increased capacity for more complex, multi-stage group assignments. This study fills this gap by targeting middle school science classrooms specifically.

The Present Study

This study aimed to explore and better understand self- and social regulation in science classrooms in the context of naturally occurring student-teacher and peer interactions. The following research questions guided this work:

1. To what degree is student self- and socially-regulated learning present in science classrooms? (Quantitative)
2. What is the nature of student SRL in relation to their teacher's: classroom environment, planning, and instruction in a science classroom? (Qualitative)
3. What is the nature of student SoRL in relation to their teacher's: classroom environment, planning, and instruction in a science classroom? (Qualitative)
4. What is the interplay between student SRL and SoRL in science classrooms? (Qualitative)
5. How does the teacher impact student regulation in the classroom? (Integrated)

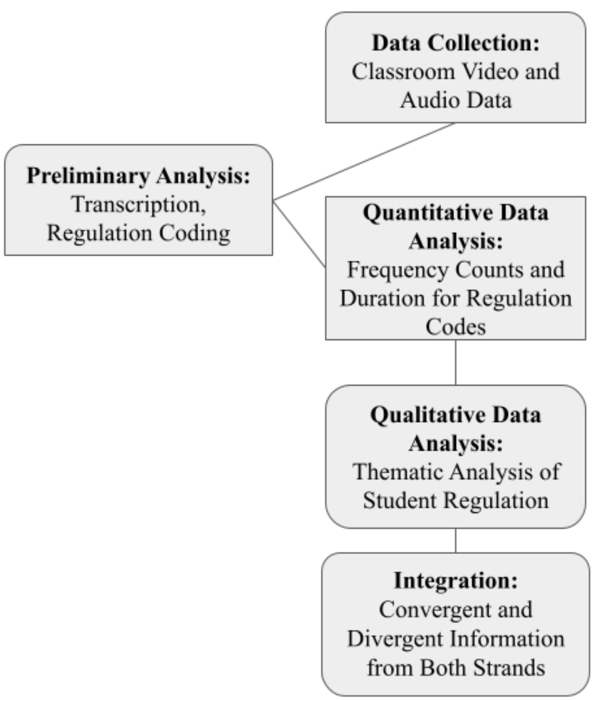
Method

Design

This explanatory mixed methods case study (Yin, 2014) has a small quantitative strand which led to a larger qualitative strand. Both informed a final integration phase (quan → QUAL; Creswell & Plano Clarke, 2018). In the first qualitative phase, classroom video data was transcribed and coded. Then quantitative data analysis was conducted to calculate the frequency and duration (elapsed time; Lobczkowski et al., 2020) of the regulation (SRL and/or soRL) segment for which codes were applied. In the second qualitative phase, coded excerpts were analyzed to describe the nature and mechanisms of self- and social regulation occurring in science classrooms. In the final integration phase, the quantitative and qualitative results were examined together to better understand student regulation occurring in the classroom, with a focus on teacher actions and student-teacher interactions. The rationale for this mixed methods approach is that both quantitative and qualitative representations of the data will provide a more comprehensive picture of regulation strategies employed in authentic classroom contexts. The quantitative results provide information about broader patterns of student self and social regulation within student-teacher interactions. The qualitative findings provide rich descriptions of the nature of student regulation and the impact of classroom features such as activity structure and interactions with peers.

Figure 1

Mixed methods design of student self and social regulation in science classrooms



Sample

This study's sample was drawn from a larger science education project focused on supporting equitable discourse opportunities for historically underserved students. Middle school science teachers were recruited from two urban school districts in a Mid-Atlantic city in the Southeastern region of the United States.

Six middle school science teachers participated in classroom observations. The teacher sample consisted of two sixth-grade teachers, two seventh-grade teachers, and two eighth-grade teachers.

Table 3

Demographics of Participating Teachers

Teacher	Gender	Age	Race	Grade Level	School Division	Years of Experience	Degree(s)
1	M	41	White	8	A	13	B.S. (Biology)
2	F	44	Black	6	B	19	B.S. (Biology); Masters (Education)
3	F	35	White	8	A	5	B.S. (Earth Science)
4	F	47	White	7	A	9	B.A. (Education)
5	F	39	Black	7	B	15	B.S. (Biology); Masters (Education)
6	F	29	Black	6	B	7	B.S. (Athletic Training); Masters (Education)

Note. School divisions (A, B) serve a student population who identify as male (51%, 50%), female (49%, 50%), and White/Caucasian (50%, 12%), Black/African American (26%, 69%), Hispanic/Latinx (16%, 15%), Two or more races (5%, 2%), Asian/Pacific Islander (4%, 2%), and Native American (< 1%, < 1%).

All participating teachers have been teaching science for at least five years. There was one male participant and five female participants. The male teacher and two of the female teachers identified as White and the remaining four female teachers identified as African-American (Table 3). Teachers selected one class period for video observation in which they intentionally planned activities that incorporated opportunities for student talk (Fishman et al., 2017). Teachers were given the flexibility to choose the class period and lesson. This enables teachers to show a typical science class period and reflect how the teachers make pedagogical choices (Fishman et al., 2017).

Our teachers served a diverse student population. Students represented in each classroom are representative of the demographics of the district. Individual student demographic data was not collected due to the classroom and teacher level analysis being conducted.

All teachers and students' legal guardians were given informed consent forms to notify them of the nature of the research and the purpose of the recordings. Teachers were offered an opt-in option for research elements of the project, while legal guardians of participating students were offered an opt-out option for their child(ren). All study procedures were approved by the institution's IRB office.

The Class Context.

Teacher 1. Teacher 1 is a White male serving in District A. Students were seated at lab tables in groups of 2 to 6. The furniture could easily be rearranged for different activities. Teacher 1 began with a warm-up activity on elements, atoms, and the periodic table that the students could complete with their groups. The class wrapped up the warm up with a discussion on nuclear fusion and fission. Then the teacher initiated small group work on an assignment they began in a previous class in which they designed their own periodic table, mimicking the trends of the periods and groups, with a category of their choosing (e.g., movies arranged by genre and by decade). Then the students were then given time to review vocabulary individually for an upcoming discussion by rewriting definitions of key scientific terms in five words or less. The class finished up with the whole class discussion, conducted in a ‘science talk circle’ in which students related the science content to historical and current events.

Teacher 2. Teacher 2 is a Black female serving in Division B. Her classroom had lab tables that were arranged in rows with a large U-shape around the perimeter of the room. Her class began with students making observations and inferences about a photograph that was projected at the front of the classroom. This was done as a whole class activity. Then, she showed a short video on the layers of the atmosphere that was accompanied with questions that students answered while watching the video. Then the class reviewed the questions and the teacher replayed the video to help students complete their questions as a whole class.

Teacher 3. Teacher 3 is a White female serving in Division A. The lab tables were arranged in clusters of 4-6 students. The students worked in pairs on experiments. They were given 3 options of experiments, chose their independent variable, and generated a hypothesis. For example, one experiment option consisted of how many drops of liquid would fit on a penny, given different types of liquids (i.e., water, salt water, vegetable oil). In this class period, students conducted multiple trials of their experiments, recorded their results and completed a lab report, including a graph of their data analysis on their Chromebooks.

Teacher 4. Teacher 4 is a White female serving in Division B. Her students sat in pairs at lab tables arranged in rows and columns. There were also lab stations with built-in cabinetry and sinks along three walls of the classroom. This class began with warm-up questions reviewing plants that students completed individually, and then reviewed the answers as a whole class. Then, using their notebooks and Chromebooks, the students traveled around the perimeter of the room to 6 different stations in groups of 3 to 4. The stations had students answering content questions about the atom. Some stations included physical or digital models. They were given 10 minutes at a station and had a timer on the board. The class concluded with some whole class directions about what to complete before the next class before the bell rang for dismissal.

Teacher 5. Teacher 5 is a Black female serving in Division B. Her classroom was arranged into small groups that combined individual tables of 2 to 5 students. The class began with warm-up questions for students to answer independently. The questions reminded students of selections they made for a poster project on African American scientists from the previous day. Students provided explanations for their choices (e.g., what made them interested in learning about a particular person) and elaborated on the stories of the scientist they selected (e.g., provide information about key historical events that were occurring during the scientists' lives). The students were then given time to work independently or in small groups on their research and posters. Halfway through the class, the fire alarm sounded and the class was out of the room for about 10 minutes. They were given the rest of the class period to work on their projects.

Teacher 6. Teacher 6 is a Black female serving in Division A. Her students were seated in groups of 3 to 4 at high top, stationary lab stations, with a couple of single desks along the front and side walls. The class began with warm-up questions that students completed independently and then reviewed as a whole class. These questions reviewed material on rotation, revolution, and Earth's tilted axis, from a previous class. The students then completed a demonstration on revolution and seasons in small groups using heat lamps and globes using directions in their notebooks. After the lab activity was completed, there were additional questions on Earth's seasons and tiled axis to answer independently.

Data Collection

Classroom Video Recordings. A full class period for each of the six science teachers were recorded in the 2019-2020 academic year by two researchers. All researchers were trained on the video collection protocol. The video observations were collected during the first (baseline) year of the ongoing 5-year project, prior to any professional learning activities with the teachers. Thus, the data represents science teachers' classroom contexts prior to the teachers receiving professional development. The teacher wore a microphone to capture the dialogue and actions of the teacher as they spoke to students in whole group, small group, and one-on-one formats. Learning materials and field notes were also collected by the researchers, noting key activity structures and transitions in the lesson and other notable events.

Classroom videos were collected using the *Swivl* technology, which includes a camera that captures a wide-angle view of the teacher and students and uploads the video to an online platform. The *Swivl* recording device tracks the teacher as they move around the classroom, ensuring that all student-teacher interactions are recorded. The videos contain a full classroom period that ranged from 48.09 to 77.98 minutes ($M = 59.18$, $SD = 14.44$) in length. In total, 360.7 minutes of classroom video recordings were collected. All classroom videos were transcribed verbatim for analysis. The transcripts differentiated between teacher and student speech.

Field Notes. During the video observations, researchers took photographs of the teachers' classrooms to capture posters, schedules, routines, directions, and examples of student work. Researchers also took notes on the flow of the classroom (e.g., time-stamped instructional shifts, transitions in activities) and any unanticipated events (e.g., fire drills, announcements from the office).

Data Analysis

Guided by the qualitative methodology presented by Miles and Huberman (1994), the classroom video data was transformed into verbatim transcripts to conduct our quantitative and qualitative analysis (e.g., Rogat and Linnenbrink-Garcia, 2011). After the verbatim video transcripts were complete, I familiarized myself with the events in the videos by reading the transcripts while playing the video.

Qualitative Documentation of Classroom Context. To elaborate on the verbatim transcripts, I systematically documented when teachers move to different students or groups of students, with a focus on the activity format (e.g., whole class, small group). I also documented non-verbal expressions of regulation that are difficult to capture in the transcripts, such as excitement, boredom, and hesitancy. Additionally, I noted physical actions of the students while interacting with the teacher (e.g., taking notes, covering their head with their hood, raising their hand; Rogat & Linnenbrink-Garcia, 2011). These physical actions and emotions will enable coders to more comprehensively code regulatory actions deductively for preliminary data analysis (e.g., writing down notes indicating the performance phase of SRL). Student actions will also provide insight to the qualitative analysis for research question two and three, which focuses on identifying contextual features of the classroom environment that influences students' regulatory behaviors (e.g., if teachers tend to approach groups who have momentarily stopped working; Ucan & Webb, 2015).

Next, I segmented each unique interaction between students and the teacher, specified by the start and end of a talk turn or meaningful episode (Hogan et al., 1999; Lobczowski et al., 2021; Murphy et al., 2018). A segment is defined as distinguishable by a change in topic or purpose of conversation (Brown & Spang, 2008; Hennessy et al., 2020; Hogan et al., 1999; Murphy et al., 2018). These segments vary in length, as determined by the duration and topic of the conversation. Short exchanges or directions were only a few lines in the transcript and seconds on the recording, while longer conversations consisted of several lines in the transcript and lasted up to a few minutes on the recording.

Preliminary Qualitative Coding. Preliminary analysis consisted of transcribing the classroom video data and applying regulation codes where applicable in Google Sheets. Coding was conducted as the video was playing. Codes and subcodes are derived from previous studies and the empirical literature (Greene & Azevedo, 2009; Hadwin et al., 2018; Heirwig et al., 2019; Truxaw & DeFranco, 2009; Zimmerman, 2002). When student regulation was detected in talk turns, the first code applied was the type of regulation observed (i.e., self-regulated learning or socially regulated learning). Then the teacher's actions related to the students' regulatory behavior were described. Researchers took note of what the teacher said (e.g., redirection, explanation) and how they said it (e.g., guiding question, direction). Student regulation was described by what they were regulating (i.e., emotions, cognition, behavior, motivation, metacognition), what phase of Zimmerman's model they were regulating within, and any specific regulation codes for behaviors that may apply (Table 4).

Table 4

Student Regulation Codes (Greene and Azevedo, 2009, Heirwig et al.,2019, Zimmerman, 2002)

Phase	Category	Codes	Examples (observable behaviors)
Forethought	Task Orientation	Exploring Task	Glancing over assignment
		Detecting Task Demands	Reviewing instructions
		Activating Prior Knowledge	Content or metacognitive approaches
		Task Perceptions	Difficulty, interest, or value comments
		Planning	Time and strategic planning
		Goal Setting	Setting own goals before learning task
	Self-Efficacy	Reflecting on One's Own Competence	Comments on what they are good or not good at
Performance	Rehearsal Strategies	Rereading	
		Memorizing	Reciting text or notes
	Organizational Strategies	Structuring Text	Highlighting
		Making Notes	Noting keywords or summaries
	Elaboration Strategies	Paraphrasing	
		Relating to Prior Knowledge	
		Relating Text Contents	Relating two or more pictures or notes
		Self-Questioning	"What do I know from this?"
	Motivation Strategies	Positive Self Talk	
		Making Tasks Interesting	
		Increasing Task Value	
		Self-Reward	
		Emotional Reflections and Modifications	Commenting on emotions (“I'm excited and can't concentrate”)
	Monitoring	Comprehension Monitoring	Understanding or lack of understanding
		Progress Monitoring	Progress made towards goal or outcome
		Interim Checking	Checking for correctness
		Affect Monitoring	Reflecting on task difficulty, interest, or value during learning task
		Behavioral Monitoring	Verbalizing actions or what they are doing in class
	Refining Strategy Use	Rereading After Confusion	
		Correcting Errors	
		Seeking Information	Student looking for textual resources (notes, textbook, websites)
		Seeking Social Assistance	Help-seeking from teacher or peer
		Environmental Structuring	Moving to concentrate
Reflection	Self-Evaluation	Evaluating Learning Outcomes	Checking task for completeness and correctness, scanning over work
		Evaluating Learning Progress	"I have studied over the task thoroughly"
		Affective Reactions	Reflecting on task difficulty, interest, or value after learning task

Note. Behavioral Monitoring was added as an emergent code.

Hadwin and colleagues' (2018) definitions for socially shared regulation, co-regulation, and self-regulation were used to identify the mode of socially regulated learning (when applicable). Lastly, the context of student-teacher interactions was adapted from Truxaw and DeFranco (2009) in which they distinguish between one-on-one, small group, and whole-class settings.

Table 5

Social Regulation in the Classroom Context Codebook

Code Category	Code	Definition
Social Regulation Mode (Hadwin et al., 2018)	Socially Shared Regulation	Student groups taking metacognitive control together to achieve a common goal
	Co-Regulation	Transactional interaction in which one individual attempts to shift regulatory practices of one or more in the group
	Self-Regulation	Individual metacognitive control
Student-Teacher Interaction Context (Truxaw & DeFranco, 2009)	One-on-One	Teacher or student is talking to one student
	Small-Group	Teacher or student is talking to a small group of students (2-6)
	Whole-Class	Teacher or student is talking to the whole class

Note. Metacognitive control refers to the processes by which students plan and execute how to complete an assignment or meet a learning objective (Zimmerman, 2002).

I coded each segment across all six classroom transcripts, and a second coder double-coded 25% of segments. We established the validity of code definitions and demonstrated an interrater reliability of 86% (e.g., Howe et al., 2019). In weekly meetings, the two coders resolved discrepancies to reach a consensus on final codes applied to the transcripts. Each coder also wrote weekly analytical memos. From these memos and meetings, one emergent code was added to the regulation codes. We added "behavioral monitoring" under the performance phase to capture instances where students explicitly referred to their behaviors (e.g., what they were doing) in the classrooms as they were completing an activity, project, or lab.

Quantitative Data Analysis. The presence of student self- and social regulation was established by reporting code frequency counts and overall time in class that regulation is visible. I quantified the frequency of each code by teacher and in total (across all six classrooms). I also reported the percentage of time in each class in which student self-regulation and social regulation was detected, as well as whole class, small group, or individual working time. It should be noted that while it can be assumed student self- and social regulation could be occurring in the classroom outside of these video observations, the scope of this study focuses on the teacher's choices and interactions with students. Thus, these frequencies and time percentages represent the quantified presence of self- and social regulation in proximity to the teacher.

Qualitative Data Analysis. Once the presence of SRL and soRL was documented in science classrooms, the second, third, and fourth research questions were answered qualitatively. I described the nature of student self- and social regulation manifestations by qualitatively analyzing the coded transcript, the video, work samples, and classroom elements (e.g. directions on the board, posters, bulletin boards). I conducted thematic analysis which consists of familiarization, coding, and theme development (Clarke & Braun, 2013; Miles & Huberman 1994; Saldaña, 2014). Familiarization occurred during the preliminary when the videos were transcribed, reviewed alongside field notes, and segmented into talk turns (Brown & Spang, 2008; Sandoval et al. 2021). Coding took place with a combination of deductive, a priori codes noted in the preliminary qualitative analysis and one inductive code that captured emergent findings (Clarke & Braun, 2013).

To answer research question two, I examined the segments coded for student SRL to determine which segments clustered together because they exhibited the same teacher and/or student behaviors or outcomes. Several themes emerged to describe these teacher behaviors and student SRL manifestations (Saldaña, 2014), including SRL emergence at the beginning of classes and the tendency for behavioral redirections.

To answer research question three, I examined the ways in which the classroom environment, lesson choices, and teacher actions have been set up to foster social regulation. Social regulation codes were isolated and grouped by similar segments and like codes into themes (Saldaña, 2014). I also coded teacher behaviors and dialogue that initiate regulation. Lastly, student regulation actions and reactions were coded. I focused particularly on how students regulate individually and/or collaboratively during and after their interaction with the teacher (Dragnic-Cindric & Greene, 2021). Several themes emerged to describe these teacher behaviors and student soRL manifestations (Saldaña, 2014) including the necessity of classroom space and layout for soRL and teachers helping students reflect and plan to complete the activity.

To answer research question four, I isolated segments that were coded with both SRL and soRL. The transition from one to the other was described from the perspective of the teacher and the student(s). For example, in a conversation between the teacher and a pair of students, the conversation may flow from what the students have to do individually (i.e., SRL) to what they must do together (i.e., soRL). These descriptions were grouped together in like categories to inform thematic development (Saldaña, 2014)

Throughout all qualitative analyses, analytical memos were also used to reflect on what I noticed in the transcripts, videos, and coding and any connections to my personal experiences or other empirical or theoretical work. I also reflected on interactions and events that surprised me in the videos (Maxwell, 2012). To aid in thematic development, I employed the constant comparison method in which I took note of similarities and differences within and between talk segments and codes in order to see patterns in teacher behavior and student regulation (Crabtree & Miller, 1999; Huberman & Miles, 2002). I used cross-case and within case constant comparisons to see how student regulation uniquely emerged in each classroom and broader patterns of regulation between multiple classrooms (Yin, 2014).

Integration. Lastly, to answer research question five, an integration phase was conducted by analyzing the quantitative and qualitative data to provide a fuller picture of how the context of the classroom elicits student self- and social regulatory behaviors. Specifically, I systematically identified and described the nature of the relationships between the authentic science classroom context (e.g., teacher directions, group size, visual directions, classroom systems and culture, student-teacher interactions) and the student self- and social regulation outcomes (e.g., regulatory strategies employed, emotional reactions, lack of planning or reflection) by comparing instances of frequent and infrequent SRL and soRL by what was occurring in the classroom.

Minimizing Threats to Validity

The awareness and mitigation of the threats to validity are important within the quantitative, qualitative, and integration phases of a mixed methods study (Onwuegbuzie & Johnson, 2006). First, video transcripts were completed by members of the research team while watching the classroom videos, rather than a third party or technological software. This helps to ensure the dialogue is as accurately captured in text as possible as the research team could slow down the video and watch it repeatedly as well as add physical movements around the classroom and details of tone and emotion. Next, all codes were derived from extant literature to establish a strong theoretical and empirical basis for the qualitative analytic scheme. During coding, all segments were coded by myself as the first author, with a second researcher co-coding 25% of the transcripts. Inter-rater reliability was calculated during double coding on Google sheets (Benedict-Chambers et al., 2017; Stein et al., 1996; Ucan & Webb, 2015). Inter-rater reliability indicated substantial agreement at a level of .85. Additionally, weekly, the coders met to discuss discrepant events within coding and their weekly analytical memos describing patterns that were emerging in the codes. I reached out to members of the research team, members of my dissertation committee, and other experts in the field to discuss patterns I was noticing during the analysis of qualitative and integration strands. Lastly, the data was triangulated; the transcripts were coded alongside the video, as well as the field notes and artifacts from the recorded classrooms. This ensured that a more complete picture of the classroom setting was accounted for, allowing for more contextualized conclusions about student regulation in science learning to be made.

Results

Findings from this sequential, mixed-methods case study are presented as follows: quantitative results regarding the presence and broad patterns of student SRL and soRL, qualitative results describing how student SRL and soRL presents in middle school science classrooms, and integrated results that provide a fuller picture of how classroom teachers provide opportunities and facilitate student SRL and soRL..

Research Question One: To What Degree is Student Self- and Socially- Regulated Learning Present in Science Classrooms? (Quantitative)

Student self-regulated learning (SRL; *n* = ranging from 13 to 60) and social regulation of learning (soRL; *n* = ranging from 5 to 59) was present in each of the six classroom videos. The distribution of the frequency of student SRL and soRL varied by class (Table 6), as did the type of interpersonal interactions or dialogue context (Table 7). The classrooms of Teachers 2 (*n* = 27) and 6 (*n* = 60) represented more student SRL segments than soRL segments. Those same two classrooms also included a high number of whole class interactions (*n* = 180 and 62). Teacher 3's classroom had the highest proportion of small group interactions (*n* = 161) when compared to whole class and one-on-one, followed by Teacher 5 (*n* = 68). Both of Teacher 3 and 5's classrooms also included more student soRL compared to SRL. Teachers 1 and 4's classrooms had a more even distribution of whole class and small group interactions. Teacher 1's classroom had more student soRL, while Teacher 4 saw a more even distribution of student SRL and soRL.

The mode of soRL was also tabulated (Table 6). In every classroom, coRL was the most common mode of soRL (*n* ranging from 4 to 45 unique instances). In all classrooms except the classroom of Teachers 2 and 4, SSRL was the next most common mode of soRL (*n* ranging from 0 to 14 unique instances). In Teacher 2 and 4's classrooms, there was no SSRL present.

Table 6

Frequency Tables for Regulation

Teacher	SRL	soRL			Total
		SSRL	CoRL	SRL	
Teacher 1	16	4	28	0	48
Teacher 2	27	0	4	1	32
Teacher 3	29	14	45	0	88
Teacher 4	13	0	14	4	31
Teacher 5	15	5	24	0	44
Teacher 6	60	4	32	0	96
Total	160	27	147	5	339

Table 7

Frequency Table and Percentages for Dialogue Context

Teacher	Whole Class (%)	Small Group (%)	One-on-One (%)		
			Student to Teacher	Teacher to Student	Student to Student
Teacher 1	93 (39)	96 (40)	11 (5)	38 (16)	0 (0)
Teacher 2	180 (80)	0 (0)	19 (8)	19 (8)	7 (4)
Teacher 3	6 (3)	161 (73)	6 (3)	35 (15)	13 (6)
Teacher 4	27 (35)	36 (47)	1 (1)	13 (17)	1 (1)
Teacher 5	46 (28)	68 (41)	8 (5)	43 (26)	0 (0)
Teacher 6	62 (32)	47 (24)	34 (18)	50 (26)	1 (1)
Total	414	408	79	198	22

The phases (Table 8) of regulation was also tabulated. Overall, the performance phase had more than twice as many instances (n = 190) than forethought (n = 70) and reflection (n =

60) and in each classroom, the most regulation occurred in the performance phase (ranging from *n* = 12 to 47).

Table 8

Frequency Table for Phase of Regulation

Teacher	Phase of Regulation		
	Forethought	Performance	Reflection
Teacher 1	10	32	10
Teacher 2	3	33	1
Teacher 3	28	47	20
Teacher 4	2	12	2
Teacher 5	17	23	12
Teacher 6	10	43	15
Total	70	190	60

The target of regulation was also tabulated (Table 9). In most classrooms, cognitive regulation was the most frequent (ranging from 20 to 44 instances). In the classroom of Teacher 6, behavioral regulation was the most present (*n* = 36). Next, Teacher 1 and 3's classrooms had the most frequent visible affective regulation (*n* = 16 and 14) and both classrooms displayed more affective regulation than behavioral regulation (*n* = 8 and 10). Motivational regulation was only present in Teacher 3's classroom (*n* = 2) and metacognitive regulation was never visible in classrooms.

Table 9

Frequency Table for Target of Regulation

Teacher	Target of Regulation				
	Cognitive	Behavioral	Affective	Motivational	Metacognitive
Teacher 1	24	8	16	0	0
Teacher 2	44	16	4	0	0
Teacher 3	32	10	14	2	0
Teacher 4	20	6	0	0	0
Teacher 5	26	24	10	0	0
Teacher 6	26	36	10	0	0
Total	172	100	54	2	0

Due to the variation in segment length (one portion of the transcript that was centered on that same topic and regulatory episode), it was also appropriate to report the time in each class spent in classroom activity structure and student regulation (Lobczowski et al., 2020). Class activity structure was broken down into whole class, small group, and individual work based on the number of students working together. Total regulation time was further broken down by type of regulation (i.e., SRL and soRL). All times were determined from the classroom videos and their transcripts (Table 10).

Table 10

Time Duration (in minutes) of Regulation and Classroom Activity Structure

Teacher	Total Class Time	Whole Class (%)	Small Group (%)	Individual (%)	All Regulation (%)	SRL (%)	soRL (%)
Teacher 1	52.1	20.5 (39)	22.6 (43)	9.0 (17)	28.9 (55)	13.0 (45)	15.9 (55)
Teacher 2	52.8	52.8 (100)	0.0 (0)	0.0 (0)	21.5 (41)	19.6 (91)	1.9 (9)
Teacher 3	71.9	1.0 (1)	69.7 (98)	1.2 (1)	49.2 (68)	16.3 (33)	32.9 (67)
Teacher 4	48.1	4.1 (9)	41.0 (85)	3.0 (6)	21.8 (45)	9.3 (43)	12.5 (57)
Teacher 5	57.9	12.1 (21)	33.2 (57)	4.6 (8)	25.4 (44)	10.5 (41)	14.9 (59)
Teacher 6	77.9	18.2 (23)	45.5 (58)	15.2 (19)	57.7 (74)	36.3 (63)	21.4 (37)
Total	360.7	108.7 (30)	212.0 (59)	33.0 (9)	204.5 (57)	98.7 (27)	99.5 (28)

Note. Teacher 5 had a fire drill within the class period. The percentages for class structure for Teacher 5 and Total do not total 100 given their absence from the classroom during that time.

Teacher 2 exclusively had whole class activities (100%) and in her class there was the least amount of manifestations of student regulation (41%), but when we did, it was mostly SRL (91%). Teacher 3 had mostly small group activities (98%) and also saw the highest percentage of student soRL (67%). Teacher 4 also had mostly small group activities (85%), but saw a more even mix of student SRL (43%) and soRL (52%). Teachers 1 and 5 had a similar trend of having proportionally the most small group time (43% and 57%) followed by whole class (39% and 21%) and then individual work times (17% and 8%). They both also had a more even distribution between SRL (45% and 41%) and soRL (55% and 59%), skewing slightly to soRL. Of all classes, Teacher 6 had the highest percentage of individual working time (19%), but still had more small group (58%) and whole class (23%) working time. They saw more student SRL

(63%) than soRL (37%). Overall, we see large variations in whole class and small group activity structures, whereas individual structures were least common and similar in range across classrooms (ranging from 0% to 19%).

4.2. Research Question Two: What is the Nature of Student Self-Regulated Learning in Relation to Their Teacher's: Classroom Environment, Planning, and Instruction in a Science Classroom? (Qualitative)

Student SRL codes were isolated. Descriptions were added to each segment, providing more details on the classroom environment, the teacher's lesson plan, and teachers' instructional practices based on the analyses of the video recording, student work samples, and field notes. These descriptions were clustered into categories, which were then clustered into themes (Saldaña, 2014). The following major themes emerged from the analyses, which are described in more detail below:

1) The physical and social (norms, routines) of the classroom environment creates opportunities for behavioral self-regulation,
2) Student SRL was exhibited in high frequencies during the warm-up and review activities of the lesson plan; and
3) teacher instructional practices elicited cognitive self-regulation after addressing behaviors.

Classroom Environment Promotes Behavioral Self-Regulation

"Behavioral monitoring" within the performance phase of self-regulation was an emergent code and added to the working codebook. This code was unique from affective and comprehension monitoring because rather than students saying how they were feeling about the task or thinking through the task, statements that represented behavioral monitoring were simply commenting on their actions on the task. This emergent code connected to the classroom environment through the physical layout and the observable social norms of the classroom environment.

Physical Environment. The physical environment of science classrooms often has unique materials and furniture compared to other classrooms. These include materials for demonstrations and experiments as well as lab tables (both moveable and stationary) and lab cabinets and countertops. All of these physical features of a science classroom related to the ways students monitored their actions and behaviors in their classrooms.

Interacting with Science Materials. Three classrooms included science demonstrations, experiments, or stations that all allowed students to observe and practice science content. In the three classes, the students used heat lamps, glassware, and electronics which require students to monitor themselves in unique ways. For example, in Teacher 6's classroom, students completed a demonstration of Earth's seasons using a 3D model of the Earth and heat lamps. These two materials and the accompanying worksheet were in the center of their lab stations. As Teacher 6 described the activity, students knew their materials would be in the center of their stations, and students told the teacher when they were missing materials. This demonstrated *planning* on the part of the students. Later in the science activity, when revolving the models around the heat lamps, several students mentioned to the teacher they were taking extra precautions around the hot, bright object and cords. One student elaborated on why they weren't going around the whole revolution by commenting, "I'm scared that that's going to touch the lamp" [*behavior monitoring; affective reactions*.] Not only was the student commenting on their behavior, but also monitoring their emotions or affect in relation to the activity.

In Teacher 3's classroom, students were conducting self-designed experiments by choosing their own independent variables for four different possible experiments. Students were responsible for getting their own materials from a common area for their specific experiment. There were several instances of students asking if the teacher was going to give them the materials they needed (e.g., eye dropper, pennies, oil), but instead the teacher pointed out the table where the materials were and had the students retrieve them [*seeking social assistance; behavioral monitoring*]. In this case, the teacher could not place every possible material at each of the student tables, so the desk with all of the materials was necessary. This could have led to distractions as students were walking around the classroom, but there was only one instance of students getting distracted by others as they were getting materials, demonstrating behavioral self-regulation.

In Teacher 4's classroom, students were rotating through stations to answer science questions related to atomic structure, look at models and visual examples, and generally review and reinforce science content. The students' desks were in the middle of the room, while the stations were on the lab benches around the perimeter of the room. There were several instances where students forgot items (notebooks, chromebooks) at their desks and they needed to leave their station to get them [*detecting task demands; evaluating learning progress*]. However, the rotation between stations was very smooth, with students knowing which way they were going and not forgetting personal items between stations [*behavioral monitoring*]. Each station had all of the materials required for it so besides the occasional trips back to their seats, students were not milling around the classroom much.

Extra Spaces to Spread Out to Work. In five out of the six classrooms, students were seated in small groups. In three classrooms, the teachers had spaces for students to work individually. In these classrooms, one or more students chose or were asked to sit in the individual seats so they could complete their work, evidence of *environmental structuring*. Teacher 1 and 5 both made statements to the whole class that allowed students to choose to move to seats to complete their work. In both classrooms, students chose to move seats and were focused to complete their work. Teacher 6 also had individual seats, but in this classroom one student, Morgan, was asked to sit at the individual desk a couple times. In the beginning of class, Morgan was seated at the individual desk for the warm up and the whole class review of the warm up. Teacher 6 had to redirect Morgan to work with his group during the science demonstration, even when Morgan wanted to stay in his seat. Then Teacher 6 had to prompt Morgan to go back to the individual desk to complete the individual work. He protested, asking to work at a different table, but she insisted he remain seated at the individual desk and complete his work. Morgan did not end up completing his work, even after multiple check-ins from Teacher 6. While it is common practice for science classrooms to have small group seating at lab tables and stations, it is important to have extra seating for students to sit independently, which may be a more optimal environment to complete individual work.

Classroom Norms. In addition to physical elements in the classroom, student SRL manifests around classroom routines and established norms.

Using Regular Materials. There were several established norms in each science classroom related to accessing and turning in materials. As examples, there were worksheets needed for the current class period and places to turn them into the teacher or keep them for future use. There were also digital resources to be able to frequently access. In four classrooms, student SRL skills were evidenced in the context of these daily routines. In Teacher 1's classroom, as students were working on vocabulary review, a student was missing a paper.

Teacher 1 asked, “Where do we get papers every day?” This reminder cued the students that they should pick up the paper from the established location.

Teacher 6 also prompted her students to glue or tape in their notes into their Interactive Notebooks. Interactive notebooks support a common science practice where students glue in notes worksheets into a notebook to keep them organized and to annotate with their developing ideas over the course of different activities (Waldman & Crippen, 2009; Young 2003). Gluing and taping the worksheets into their notebooks happened in under two minutes and students were sharing resources. Later in the class period, students also had to turn in the worksheet from their activity. The students knew to turn in assignments on the teacher’s desk. This was evident from the lack of prompting the teacher did except to one small group of students.

Routines were also evident around the use of digital materials. Teacher 3’s students were writing their lab reports on their chromebooks. With minimal prompting, her students cleaned up their experiments and then opened their chromebooks to make tables and graphs representing their data. They did not ask where they needed to be working, showing they knew where to complete this work. With only one whole class direction, Teacher 4 instructed her students where they could find the questions for their lab stations. The students seemed to be used to these directions because they did not ask additional questions about where to find this digital resource.

Unlike the other teachers, Teacher 5 had some new materials in her classroom for her students to use to complete their project. Therefore, students were exhibiting a combination of SRL skills. Students frequently asked the teacher for the new materials (e.g., Sharpies, poster board) that they were unfamiliar with. For the first part of the small group work, the teacher was weaving around the classroom accommodating student requests for materials. Conversely, students knew where common materials (e.g., rulers and markers) were, so Teacher 5 could simply say, “You know where those are.” Students would then go get the item themselves. It was noted that even with common materials, students were asking for assistance more often than in other classes.

Openly Seeking Assistance. Across the classrooms, there was a variation in the frequency of students seeking assistance from their teacher. The students in Teacher 4, 5, and 6’s classes frequently asked for help from their teacher. These questions ranged from where to find materials around the room to help answering more in-depth questions in their science lessons.

Student: How can we print off a picture?

Teacher 5: All right. So if you want to print a picture, you can email it to me. [Teacher’s email]. It’s on the board.

Teacher 5: You don't have to print your pictures off. You can draw your stuff.

Student: I can't draw

In this excerpt, the student asks how they can print off a picture for their poster and later says they can’t draw. This shows that the student knew a picture had to be on their poster, but they recognized their lack of drawing ability. They were comfortable enough with their teacher, and self-regulated to ask for the printing alternative and admit their inability to draw well.

In this next excerpt from the same class, a student is seeking assistance in finding information for their poster.

Student: It's no stuff on him. Every site I go to, this is what it says.

Teacher 5: What fact are you looking for?

Student: Where he lived?

Teacher 5: So...did you open up the link

Student: I did. It's right here. It's nothing. It's not him

Teacher 5: Why do you say it's not him?

Student: This is somebody else...inaudible

Teacher 5: So what are you looking for that you feel is not there?

Student: Where he lived at.

Teacher 5: Okay. So go back up to...what happened is a lot of the modern scientists, it's like they don't have a lot of research about where they grew up and stuff available on the computer. So you can try some other places and if you can't find anything, we'll just...it's up to you, but you might want to switch your person. Okay, Let's see what you can find out. Open up another tab. Let me see you search again.

This demonstrated progress and comprehension monitoring on the part of the student, in addition to feeling comfortable to seek social assistance. This compliments the previous example by showing how a student was working through a more cognitive problem with the teacher.

The previous examples were contrasted by the students in Teacher 1's classroom. When Teacher 1 walked around to check on his students, students would be stuck on a question, but did not ask for help.

Teacher 1: How are you doing?

Student: Not good.

Teacher 1: Why didn't you ask for help?

Student: I don't know.

This student was demonstrating monitoring by saying they're "not good", but the reason for not asking for help is unknown. While that is one example, this teacher saw quite a few students stuck on elements of different activities, which had him actively initiating check-ins with students more often.

Elements Early in the Lesson Plan Influenced Student Self-Regulated Learning

The highest concentration of SRL codes were within the first 10 minutes of the class periods. These codes were typically in the forethought phase, including *activating prior knowledge, detecting task demands,* and *planning*. From those codes, the following were important features from the lesson plan that helped students' SRL.

Warm-ups and Content Review. In most of the classrooms, the class period started with a small warm-up activity or time to review content from a previous day. Teachers 1, 4, 5, and 6 all began their classes with questions that reviewed content that was the focus of the rest of the lesson. Each individual student was able to answer the questions individually and then the teacher would review the answers with the whole class. These questions were mostly vocabulary and science concept review. This helped students remember important information before starting the projects, stations, and science activities, demonstrating *activating prior knowledge*.

One exception was Teacher 4. In her classroom, part of the warm up also asked students to reflect on why they chose their African American scientist and why it was important to focus on African American scientists. This prompted students to think about the reasons behind their learning choices and the purpose of the project [*evaluating learning outcomes; relating to prior knowledge*]. This demonstrated reflection as well as forethought with verbalizing *task demands*.

Another unique version of the warm-up activity in Teacher 2's classroom. This class started with students individually writing an observation and inference from a photograph projected on the board. The class proceeded like many of the others, but instead of stopping after a few minutes to go on to the next part of the lesson, Teacher 2 continued prompting student responses (for approximately 30 minutes of the class period). This extended warm-up activity provided opportunities for students to exhibit cognitive SRL ["And what made you think of that inference?"; *relating to prior knowledge*] as the teacher asked follow-up questions and had the students explain their reasoning. Instances of SRL breaking down at the end of the activity (e.g., students were asking to get water and go to the bathroom and even getting distracted and falling over in their chairs; *behavioral regulation-Not Present*).

Written Directions on Board and Worksheets. When transitioning from the warm-up to the class activity, it was important for teachers to give clear verbal directions. Teachers 1, 4, 5, and 6 also used visual reminders for their students to refer back to throughout the lesson. Teachers 1, 4, and 5 used the board to write important pieces of information, such as goals of the project, content review (e.g., a Periodic table to reference, picture of an atom), and the time remaining in an activity. Teacher 1 projected a timer on the board for students to help keep track of time. Several students commented on not having a lot of time left, showing they used this resource to strategically manage their time [*planning*]. Written directions on a worksheet or digital learning platform were also common. Teachers 3, 4, and 6 not only had these resources available, but when checking in with students, would turn their attention back to those written directions so the students could remind themselves what they needed to be doing [*detecting task demands*].

Teacher Instruction Redirects Behaviors and Deepens Thinking

Teachers' moment-to-moment instructional choices made throughout the lesson helped students regulate their behavior and thinking. Specifically, presented below are illustrations of such instructional choices including teacher behavioral redirection, questions, and wait time that supported students' behavioral and cognitive self-regulated learning during primarily the performance phase.

Individual Behavioral Redirections. Individual behavioral redirections were observed in all teachers' classrooms. For example, Teachers 3 and 5 used questions to help students reflect on their behaviors. Commonly they said, "What are we/you doing over here?" This prompted the student to verbalize his behavior [*behavioral monitoring*] and correct their behavior. Teacher 6 used more direct means of redirection. She initiated the conversation by telling her students what they should be doing. Often the student would frame their behavior by saying, "I was just…" but then came around and got back on task.

Importantly, all three teachers did not raise their voice or become visibly angry or upset with their students. They spoke in a straightforward, neutral tone and language. Additionally, they approached the student and redirected them privately, which was important for maintaining respect for the student.

Teacher Questions. Teacher questions were most commonly associated with supporting students' cognitive SRL. Sometimes, they came in the form of a brief check in with students (e.g., "How's it going over here?"). Teachers' questions prompted students to make a real-time evaluation of their learning progress and verbalize whether they needed help or whether they were on track with the goals of the learning activity (e.g., "I'm good") [*evaluating learning progress*]. Teacher questioning approaches were also more sophisticated, which supported students' SRL by having them elaborate their ideas [*performance*]. An example of this is in Teacher 2's classroom, where students were sharing observations and inferences from a series of photographs.

> Teacher 2: What more can we find? Alright. Throw it up here (ball/speakerphone) to [Student] and try not to hurt him. Alright good job. Speak into it.
>
> Student: Umm. This is in Europe?

Teacher 2: Okay. So [Student]'s observation was that this was happening in Europe. What in the picture makes you say it's Europe?

Student: Because the buildings they have those buildings like apartments they have in New York.

Teacher 2: Alright so [Student]'s observation is that they have apartment buildings that look very similar to those in New York.

In this excerpt, the student initially reports an inference (i.e., the judgment they are making about the picture). Teacher 2 asked them a follow-up question that encouraged them to expand on why they were making that inference. The student's response showed that they were using their prior knowledge of buildings in New York and connecting it to what they inferred that housing in Europe looks like [*relating to prior knowledge*]. Teacher 5 also asked follow-up questions to a student sharing out why they chose a specific African American scientist for their project. Like in Teacher 2's classroom, these questions elicited student's prior knowledge and how they were connecting it to the current project.

Wait time. Wait time (a period, approximately 10 seconds, of silence after a question is posed) gives the student time to collect and convey their thoughts and ideas. Wait time was often associated with manifestations of student SRL in the classrooms. Teachers applied wait time verbally when checking in with students. For example, Teacher 3 provided ample wait time for her students and asked additional questions to correct their responses throughout the conversation:

Teacher 3: Okay, so how do you calculate speed?

Student: Divide distance and time.

Teacher 3: So you divide the distance divided by time? So what do you need to know?

Student: The distance.

Teacher 3: What unit should we be using?

Student: Inches

Teacher 3: Try that again?

Student: Centimeters. Oh I thought that was.

This excerpt highlights that Teacher 3 saw an issue in the student's calculations and guided them back on track through questions [*evaluating learning outcomes*]. The student was given time to answer and asked follow-up questions to correct themselves in the learning process.

Overall, student SRL was observed in the classroom through both silent actions (e.g., finding materials and writing responses) and in dialogue (e.g., through responses to teachers' follow-up questions). It occurs behaviorally and cognitively for the most part, and for most of these cases, clustered at the beginning of classes.

Research Question Three: What is the Nature of Student Social Regulation of Learning in Relation to Their Teacher's: Classroom Environment, Planning, and Instruction in a Science Classroom? (Qualitative)

The science classroom context is a dynamic, social space for students to learn, particularly when students are engaging in inquiry, collaboration, and argumentation. Findings demonstrate the variety of ways teacher choices can foster students' social regulation of learning (soRL). The following main themes related to teacher instructional choice and students' soRL will be described in more detail:

1) The physical layout of the classroom can enable social regulation of learning

2) Features of collaborative lessons and activities that activate soRL

3) Teachers' active monitoring of small groups that supports sustained student soRL throughout a collaborative activity

Classroom Environment Allows for Group Collaboration

The layout of the physical classroom environment was important for allowing students to engage in co-regulation (coRL) and socially shared regulation (SSRL). They need to be facing in a way they can talk to each other and spaced out from other groups to maintain focus on their own work or their group's work. Various physical layouts were documented across the six classrooms, including individual desks grouped together, free standing stations, and desks arranged in a circle. Each of these presented opportunities, but also sometimes barriers to soRL. These findings are presented next.

Physical Spaces for Social Regulation of Learning. When student soRL was present, students were typically seated or standing in groups facing each other. They were either using movable or stationary furniture, common to science classrooms. Movable furniture includes single student desks and chairs that can be rearranged into small groups, allowing for easier student coRL and SSRL. Stationary furniture includes lab benches and countertops that are too heavy to move or that are fixed to the floor. These can promote student coRL and SSRL if the students are arranged in a configuration that allows them to face each other. But it can also hinder it if the students are all facing the same direction. These arrangements are harder or impossible to change lesson by lesson.

Teacher 5 had classroom furniture most similar to a non-science classroom. Her room only had individual desks. To facilitate group work, she had arranged the individual desks into clusters with students facing each other so students could freely share ideas [*SSRL*; *coRL*].

Teacher 4 also had individual desks. They were arranged in rows in the middle of the classroom with lab countertops on three of the four walls. While most of the SRL occurred in the individual desks during the warm up, the soRL occurred while small groups of students answered science questions at stations set up on the lab countertops [*coRL*; *comprehension monitoring*]. However, this was still not an ideal set up given the students were still working in a line and could not speak freely to all group members if the groups were larger than 2 or 3. When groups of 4 were placed at a station together, students on the periphery of the group would work by themselves and were more likely to ask Teacher 4 for help as they were passing by [*SRL*; *seeking social assistance*], rather than their group members.

Lab tables that seat two students are more common to see in science classrooms and provide teachers with choices on how to arrange their students, which either promotes or inhibits soRL. Teachers 1 and 2 had their lab tables arranged around the perimeter of the room with some pairs in the middle, modeling stadium seating. All students could face the front of the room easily. Teacher 2 directed learning for the whole class for most of the class period, but collaboration would not be easy for her students given their seating arrangement. They could only talk to partners directly next to them. She had them use this strategy once during class [*SSRL*; *relating to prior knowledge*]. Teacher 1 facilitated more soRL by allowing his students to move their chairs and cluster around the rows in groups of 3-4. Moving their seats to face each other allowed students to easily share ideas and examples for their atoms project [*SSRL*; *relating to prior knowledge*]. Teacher 1 also moved the chairs in his classroom to facilitate a whole class discussion. He had students move their chairs to create a circle. This circle enables a conversation connecting science concepts they were discussing in class and real-world phenomena [*SSRL*; *relating to prior knowledge*].

Spontaneous Social Regulation of Learning in Small Groups. In two classrooms, students were seated in groups facing one another that facilitated soRL. Teacher 3 had her lab tables facing each other, while Teacher 6 had fixed lab tables that seated 3 to 4 students in a circle. Both configurations allowed students to monitor and evaluate their groups' comprehension and progress by allowing students to share materials and speak easily in small groups [coRL; SSRL]. Interestingly, we observed moments of soRL that were not prompted by the lesson plan or activity's directions. For example, in Teacher 3's classroom, students worked in pairs on their choice of experiments. These pairs were seated next to each other and there was another pair of students seated directly across from them at an adjacent lab table. With this set up the pairs of students were able to see not only their experiment, but the other students as well. Because of this, students were reacting not only to their experiment but others.

This setup was conducive to students becoming interested in different science phenomena including not only their experiment, but the experiment of another group [*affective monitoring*]. For example, two boys who were completing a ramp lab with toy cars communicated interest in the liquids on a penny lab of the other pair at their table:

Student 1: [Teacher 3], can I do that one time?

Student 2: Can he try it, [Teacher 3]?

Teacher 3: When his (Student 1) experiment is done. You (Student 2) have to finish yours.

Student 1: [Teacher 3] that, I want to do that one. Look at it, look at how it stay on the penny.

Teacher 3: You wanted the challenge. When they figure out what causes that, they're going to let you know when they present their poster after break.

This excerpt shows how easily observing scientific phenomena can activate positive *affecting monitoring* and *affective reactions*. The student saw water forming a large bubble on top of the penny and rather than falling to the paper towel below, it kept holding more and more drops. He wanted to try to see how many drops of water he could fit on the penny [*task perceptions*]. Teacher 3 tied the phenomena to scientific inquiry by elaborating with "When they figure out what causes that, they're going to let you know when they present their poster after break." This opportunity for student and teacher co-regulation would be less possible if the student groups weren't facing each other.

However, the combination of pairs at the same table sometimes also resulted in distracting students, or events that triggered a deterioration of soRL. For example, two students who chose an ice melting lab saw the toy cars for the ramp lab and wanted to swap so they could "play with the toy cars" [*affective monitoring*]. Because they had already written their question, hypothesis, and procedure, they were unable to switch. Also, when the students were done collecting their data, they were instructed to make the data tables, graphs, analysis, and slides for their presentations on their computers. With some pairs still collecting data, those on the computers sometimes had to be redirected by the teacher to focus on their own work [*behavioral monitoring- Not Present*].

Similarly, Teacher 6's classroom had stationary lab tables where students were facing each other, which presented tradeoffs in terms of supporting and creating barriers to students' soRL. While this was helpful for completing their science activities in their table groups, it also allows students to talk to each other during individual working time. For example, after their group science activity, the students were instructed to complete the extra questions on their own; however, the lab tables made it conducive for students to start chatting with one another instead.

Teacher 6 had to direct this message to the whole class in the middle of individually talking with students [*behavioral monitoring- Not Present*].

> Teacher 6: You good, [Student1]? Do you have any questions? Give me one second. *If you are working on this paper, it's independent so I shouldn't hear no talking. It's a lot going on in here and I'm real confused on why.* You need one? You're working on that. You're working on this, [Student 2]. You have to answer these questions on the back. Here's the paper.

This not only highlights a whole class redirection and how students will naturally want to talk in groups if they are seated near peers, but also a common teacher action of pausing a conversation with an individual student to address the whole class.

The findings presented here demonstrate the idiosyncrasies of setting up a classroom environment that supports students' soRL. That is, as described here the same physical grouping presents affordances and challenges to student soRL.

Planned Activities Can Differentiate the Amount and Type of Social Regulation of Learning

Science lessons can have a variety of types of activities. These activities can lend themselves to students' soRL. Not only did the type of activity relate to the presence of student soRL, but also the mode (i.e., SRL, coRL, and SSRL), target (cognitive, behavioral, motivational) and phase (i.e., forethought, performance, and reflection) of soRL.

Completing Work in Small Group Setting. Completing a common set of questions to help reinforce science concepts in a small group setting was a common lesson feature across science classrooms. For example, Teacher 4 chose to have students answer questions in small groups as they rotate through lab stations. During this activity several student soRL behaviors were observed as students were moving their computers and notebooks to each lab station, answering the questions in small groups, and moving to the next lab station. They knew the protocol for focusing on work at their lab stations and how to quickly and quietly switch stations [*behavioral monitoring; planning*]. They were intent on finishing the work, asking what to do if they didn't finish questions at a certain station [*SRL*; *seeking social assistance*; *evaluating learning progress*]. However, most of this soRL exhibited by the students was coded with the *SRL* mode of soRL and a limited number of students co-regulating [*coRL*] with each other.

Most co-regulation was from one-on-one or small group discussions with the teacher. These conversations were helpful for students struggling with answering the content questions. For example, when two students had different answers to a question, they struggled to know who was correct. They called Teacher 4 over to their group so she could tell them who was correct. Teacher 4 went to the whiteboard to scaffold students thinking around the topic [*coRL*; *seeking social assistance*].

> Teacher 4: Alright so, okay so which one is two or more?
>
> Student: She said this one
>
> Teacher 4: Okay so individual elements. How many individual elements do I have? How many items can I count? Oh b, she's talking about b. How many total do I have? So how many atoms do I have?
>
> Student: 1
>
> Teacher 4: Okay good. but then how many Cl's do I have?
>
> Student: Oh 3
>
> Teacher 4: why three?
>
> Student: [no response]

Teacher 4: Because this coefficient goes with everything here. so I have 3 Na's and 3 Cl's I have a total of

Student: total? 6

Teacher 4: I have a total of 6, mhmm, mhmm. It's just like if I were to write, ladies watch here, how many x's do I have? 2. If I were to write what do I have? hmm 2 x's anndd 2 y's. It's exactly the same thing even if I have variables here. it's the same thing as if I did ---- okay? make sense now?

This excerpt highlights several key soRL processes occurring within this small group work time. First, these two students were collaborating on some level to at least check answers with each other, an example of *progress and comprehension monitoring*. Secondly, the students are regulating themselves by knowing to take a step back from their own conversation and seek assistance from the teacher, an example of *socially shared regulation*. When the teacher did come over, she transitioned the regulation to *co-regulation*, where she was using cognitive scaffolds of *activating students' prior knowledge* and connecting chemistry to math. Lastly, the teacher doesn't actually say which student is correct, she helped them realize the correct answer through her example and then left them to complete their work independently [*SSRL*].

Collaborating on Group Labs and Projects. When students were working together on science labs and projects, there was more evidence of soRL and more examples of student-led modes of soRL (e.g., SRL, CoRL, SSRL). For example, teachers 3 and 6 had students working on science experiments and demonstrations. These activities were associated with students discussing what they were observing and doing [*behavioral monitoring; paraphrasing*], connections to science content and prior knowledge [*relating to prior knowledge*], and making progress towards the group goals [*progress monitoring*]. These discussions took place with and without the teacher present in the group [*SSRL*].

In the following excerpt, Teacher 6 is going around the classroom to check on student work as they complete a demonstration on seasons.

> Teacher 6: What you guys can do next is you can draw a picture of what you did. Give me that. This ain't showing me all the seasons. This is showing me one season.
>
> Student: I have to draw four?
>
> Teacher 6: Yeah.
>
> Student: What is the picture supposed to be?
>
> Teacher 6: Show me what you guys did.
>
> Student: We had to move that because it had almost hit the fan.
>
> Teacher 6: How did you model the seasons?
>
> Student: We took it and rotated it.
>
> Teacher 6: You rotated it? Like this? This is just day and night. I'm trying to see a season.
>
> Student: Where's the pieces?
>
> Teacher 6: How do I see a season? What are you doing?
>
> Student: It's revolving.
>
> Teacher 6: Are you?
>
> Student: I mean, revolving.
>
> Teacher 6: Right, so to see the seasons, you have to do what?
>
> Student: Revolve.
>
> Teacher 6: Revolve it.
>
> Student: This is winter. This is spring.

Teacher 6: Where's winter? If you're right here, where's winter? No. We do it northern versus southern hemisphere. Which one is tilted towards the Earth?

Student: Wait, I was supposed to tilt it this way or this way.

Student: Now, it's spring.

Teacher 6: Yeah, what is it up here?

Student: Summer.

Teacher 6: Then what is it down here?

Student: Winter.

This excerpt highlights coregulation led by the teacher. There was a clear shift in understanding from the beginning of the passage where the student incorrectly answered that the earth's rotation represented different seasons to the end of the passage where it was evident that the student understood the difference between rotation and revolution. There was also evidence of *progress monitoring* and *correcting errors* exhibited by the students, as they received the teacher's feedback and made changes to how they were simulating the seasons (recognizing that season changes related to a revolution around the sun rather than the earth rotating around its own axis) [*planning*].

Similarly, Teachers 1 and 5 had student groups working on science projects (i.e., periodic tables and posters of African American scientists). There were students working toward group goals [*soRL*], but compared to labs and demonstrations, with these worksheet-based projects, their soRL was characterized primarily by behavioral targets of soRL. With these projects, the student groups were focusing on completing the work [*behavioral monitoring*] rather than interacting with or learning the content [*comprehension monitoring*]. For example, in Teacher 5's classroom, the students were conducting research on an African American scientist and reporting their information on a poster [*seeking information; paraphrasing*]. Often students split up responsibilities such as having some group members work on the research, while others designed and drew the poster. Therefore, students were working mostly independently, an example of the *SRL* mode of *soRL*. Sometimes this would lead to disagreements between group members that they then sought out the teacher to help resolve [*affective monitoring; affecting reactions; seeking social assistance*].

Teacher 5: [Student 1] and [Student 2], I don't know what you guys are doing, but I need you to focus, okay? So here's the deal. I did and I'm going to ignore it for a second. You have five questions that you are working on.

Student 2: He like to do all the work. He taking up the board.

Teacher 5: Which question are you working on, [Student 2]?

Student 2: He like to do all the work. He ain't letting me do nothing.

Teacher 5: Which question were you working on [Student 2]?

Student 2: Where he lived.

Teacher 5: So what question are you working on [Student 1]?

Student 1: I can't do nothing because he doing all the work. I draw. I drew.

Teacher 5: So that's the thing, there are five other things that have to be on this paper. But I need you to understand that you've been working on this for quite a bit of time now so there should be more on this paper than just her name and y'alls names. Okay?

Teacher 5: I need you to breathe.

Teacher 5: Seriously and I really think you guys could do more as far as talking about what you're putting on the poster. Cause he's allowed to draw lines.Get a different marker honey and help him. That's what I would suggest.

Teacher 5: You could be finding information that answers the questions. Do you have answers to all five of the questions?

Teacher 5: So… Wait a minute, let's listen for a second. Do you have answers to all five of the questions yet? Do you have answers to any of the questions yet? The five facts that will be on your paper. Like these. When they lived, where they grew up. Do you have any of those answers?

Student 1: What did you do with the Chromebook bruh?

Teacher 5: There's one right here. Is that y'alls? You should be looking for answers. You gotta work together.

This excerpt highlights several targets and stages of regulation. The teacher was attending to the students' emotional, behavioral, and cognitive regulation by having the students verbalize their *progress monitoring* and helped develop a new plan for moving forward [*planning; task perceptions*]. Student 1 started to internalize the newly established plan by asking where the Chromebook was, showing he knows he needs the Chromebook to answer the questions for the assignment [*detecting task demands*].

Cogenerating Ideas in Whole-class Conversations. The activity structure in which the most cognitive soRL was identified was in the talk circle, led by Teacher 1. Just before the talk circle, the students were reviewing science vocabulary by summarizing scientific definitions in 6 words or less. Then, with the science vocabulary worksheet and the abbreviated definitions as a reference, students and Teacher 1 formed a circle of chairs and began discussing how the science content they were covering in class connected to their lives and historical events.

Teacher 1: Okay, when you have chemicals in your food...what specifically did I point out is in some of your food?

Student 1: Lead

Teacher 1: Well there is lead in our water that's why we don't drink out of the sink. We have lead and mercury in the sink water in this school.

Student 2: Well I drink it

Teacher 1: Well that could give you brain damage.

Student 3: The water fountain? Who don't drink the water from the fountain?

Teacher 1: No the sink

Student 4: Not the school sink?

Teacher 1: Yes, the school sink has lead and mercury in them.

Student 1: We can drink at home though right?

Teacher 1: Yeah you can drink out of your tap at home. Just not at school. They are filtered first of all. The problem is the pipes that are used for the sinks are really old. So they have mercury and lead holding the pipes together. They just rebuilt this school

This excerpt illustrates the free flow of ideas in the talk circle [*coRL*]. Teacher 1 posed a question so the students could *activate prior knowledge* to their own examples to science concepts [*relating text contents*]. Several students contributed to the flow of thoughts and the teacher used their expertise to help facilitate and clarify ideas. This type of planned activity promoted coRL and SSRL by facilitating conversation in the whole class, where students were making spontaneous connections to everyday events (e.g., school sink, water fountain) and actively asking a series of questions related to the phenomena at hand (e.g., getting sick from drinking sink water) [*elaborative strategies*].

Active Monitoring and Teacher Interventions Ensure and Maintain Social Regulation of Learning

During small group working time, where most of the soRL occurred, teachers walked around the classroom to monitor students' progress and check-in with students. This monitoring and intervening varied by teacher. Teacher 4 circled the classroom often, looking at student work to check progress and typically only stopping to help when a student asked [*seeking social assistance*]. In contrast, Teachers 1, 3, and 6 stopped at each student group as they passed to verbally check in and see how the students were doing. Sometimes the students verbalized they needed help while other times they said they were okay [*evaluating learning progress*]. This self-evaluation of their collective progress was a clear indication of their *soRL*. When teachers checked in for longer periods of time, they typically did so to clarify directions and redirect behaviors, facilitate students' understanding, and help them evaluate their progress to plan to complete the activity.

Behavioral Regulation and Clarifications. When the small group activity started, teachers would typically focus their attention on ensuring students knew what to do [*detecting task demands*] and had the materials they needed [*planning*]. These interactions were quite short, lasting less than a minute. They would use visual cues (e.g., seeing if students had materials out and set up) or verbally check-in with student groups to ensure the groups got started on their assignment. They would use verbal redirections when necessary. For example, when there were distractions in the classroom, Teacher 6 would often ask, "We good?" and address behavioral concerns [*behavioral monitoring-Not Present*].

Facilitating Student Understanding. After student groups were set up in their activities, teacher questions largely began to center around student understanding. These tended to be longer conversations with students. Teachers were asking questions to ensure students were making observations relevant to the science phenomena and making meaningful connections among key science concepts. For example, while students were completing their designed experiments in pairs, Teacher 3 would work with the pairs to prompt them to verbalize and correct their understanding [*correcting errors; comprehension monitoring*].

Teacher 3: What are your two things on a graph?

Student: The time and the place, I mean the surface.

Teacher 3: The time and the independent variable. So you're independent and which axis is your dependent?

Student: Y

Teacher 3: Y. so what was your dependent variable?

Student: Surfaces, no the time, the time

Teacher 3: The time? So then you need to draw your axes, right? Put your dependent on the y axis? Would you like a ruler?

Student: I'mma just copy the line

Teacher 3: Okay, Okay, so your dependent is going on the y, what's going on the x? What's on the x?

Student: The independent

Teacher 3: Your independent, and what was your independent variable?

Student: The platform and the ball

Teacher 3: This is your grade, too (to Student 2)

Student 2: I know

Teacher 3: What was your independent?

Student: The ball and see now you got me nervous and now I'm sweating.

Teacher 3: Ok, so your surface, right, your terrain?

Student: It's your fault, you got me off track. (To Student 2)

Teacher 3: Your terrain needs to be here. You need to label, right, on a graph? Label your terrain here and what were you measuring?

Student: The surface

Teacher 3: No

Student: The time

Teacher 3: The time. So time here, terrain here and that needs to be entered into the data table. Do you know how to... You know how to enter a table? You just had a data table. Where did it go? Yeah, see you just had your data table here. So you need to say like terrain, right? Ball 1, ball 2, right and then times.

This excerpt highlights how Teacher 3 sat and helped the student understand their data and how to graph it [*relating to prior knowledge; correcting errors; behavioral monitoring; planning*]. Rather than telling the student which data points were associated with which axis, the teacher asked questions to connect the data students collected to independent and dependent variables and common graphing conventions in controlled experiments.

In summary, small group, collaborative activities, in clustered seating arrangements, promoted student soRL. Teachers' in the moment actions, such as behavioral redirections and conversations to facilitate students' understanding, help ensure students' have positive soRL learning environments.

Research Question Four: What is the Nature of the Interplay Between Student Self-Regulated Learning and Social Regulation of Learning in Science Classrooms? (Qualitative)

Because students have to work both independently and collaboratively in the science classroom, self and socially regulated learning are inherently connected. Students complete their own work and are individually accountable, but also are surrounded by peers and their teacher and often tasked to work with others. The following main themes will be described in more detail:

1) Social Regulation of Learning emerged from Self-Regulated Learning when the teacher engaged students in dialogue after the student seeks social assistance
2) Self-Regulated Learning emerged from social regulation of learning when students internalize regulatory practices from the teacher

Social Regulation of Learning Emerging from Self-Regulated Learning

A common display of student SRL in the classroom was *seeking social assistance*, usually by calling the teacher over to ask a question. When responding to the student, teachers typically did one of two things. One way teachers responded was by answering the student's question directly with a quick answer and moving on to other student(s). This was mostly seen with help with materials (S: "Where are the markers?" T: "They're in the cabinet.") But it also occurred with procedural struggles too (S: "When I'm measuring it, should it be like this or like this?" T: "I would do the diameter."). Lower level student questions like where to find something and what to do were often just answered for the student, ending the regulatory episode.

For questions related to science concepts, student questions were handled in a different fashion. Teachers would spend a longer amount of time with the student or students and initiate *coregulation*, led by the teacher. When working on a small group project making their own periodic tables with everyday items, Teacher 1 is called over by a student to help with the cognitively taxing assignment.

Student: I need help.

Teacher 1: Okay I'm here to help.

Student: What do you mean about one of them....

Teacher 1: Alright, you're doing sour candy right?

Student: Yeah.

Teacher 1: So each column is going to be a type of sour candy. So how are you going to name each column? What are you going to differentiate them by?

Student: My partner's not here.

Teacher 1: So you've got to brainstorm. That's what you've got me here to brainstorm. But I need you to come up with the ideas. I can't give you all the ideas. So how sour...how much sour it is? So you're increasing by how sour it is right?

Student: Yeah.

Teacher: In each column. So what are your columns going across? Your groups, up and down, your families. How are they similar? You should have them written down. So you said groups of where they are made. So you're going to do sour candy from different countries.

Student: Yeah.

Teacher 1: So what's going to increase? What's your atomic mass going to be as you're going down? Atomic mass is going to be increasing in sourness right?

Student: Yeah.

Teacher 1: Okay, you already got that I think. You got how sour it is. So what are you going to name them? Won't you just name them by country?

Student: Uh yeah like…

Teacher 1: Mhm, now do you get it?

Student: Sour candy by country maybe. Okay

By saying phrases like “I’m here to help” and “you’ve got me to brainstorm”, Teacher 1 was signaling that he was co-regulating with the student to guide their understanding rather than just tell them the answer. He used the students' ideas and helped the students see they were on the right track all along. In this case, the teacher was co-regulating with a single student.

Another way the teachers would initiate co-regulation would be to help the student and open up the conversation to the group, recognizing that others would benefit from this. This can happen when it is a common student misconception of a common issue teachers are noticing around the classroom.

[Student 1 raises their hand]

Teacher 1: Fission we just did. Is that coming together or splitting?

Student 1: Splitting

Teacher 1: Atoms splitting. [speaking to the whole class] *Hey guys, in fission. When the atom splits, when the nucleus splits, what is given off?* [inaudible classroom mumbles] *I'm asking the whole class. In fission, when the atom splits, what's given off?* [inaudible student response] *What? I can't hear you.*

Student 2: Energy?

Teacher 1: *Energy, and what particle*?

Student 2: Uh.... neutron.

Teacher 1: *Neutron. Energy and neutron. Energy and neutron is given off. Right here.*

Here, Teacher 1 supported the student in asking for help [*seeking social assistance*], but also supported the whole class reviewing a piece of difficult science content. This emergence of soRL from SRL was frequently observed across classrooms

Self-Regulated Learning Emerging from Social Regulation of Learning

Student SRL also emerged from moments of coregulation with the teacher. This is different from the SRL mode of soRL because the SRL mode of soRL still highlights how the individual student is working toward the group goal (S: "Well I was working on the poster"). SRL emerging from coRL occurred in two main ways, the student summarizing what they need to do next and the student applying what the teacher said to their work.

Teacher 4: How are you guys doing? ...

Student: Good?...

Teacher 4: Sure? huh, at least looking that up but you also have that where?

Student: In my notebook

Teacher 4: uh huhhh

Student: I can just look it up.

Here, Teacher 4 was helping the student know where to find the information they were seeking. The student ended the conversation by restating what they can do in a slightly different way [*paraphrasing; planning*], showing they have processed the information and know what they need to do next, thus going from *coRL* with the teacher, to *SRL*.

This also occurred when the student applied something a teacher has been helping them or the class with. In contrast with the previous example, it occurred later in the class period, rather than at the end of the conversation with the teacher. In Teacher 6's class, she asked the students to write their answers in complete sentences on the content questions after their Earth demonstrations. She repeatedly verbalized the *task demand* to individual students, small groups, and the whole class. At first, she was going around to tables of students and prompting them to rewrite their answers in complete sentences (Teacher 6: "How do you say this in a complete sentence?") and prompted the student until the student had verbalized a complete sentence. She then said, "Write that down." A few minutes later, a student at a table she had already visited raised their hand and asked, "How do I say this in a complete sentence?" This shows the student has internalized the *task demand* and is *seeking social assistance* to help them meet those demands. The former act of internalization is a hallmark of co-regulation; that is, the student is demonstrating self-regulatory behavior following the co-regulation interaction.

Research Question Five: How Does the Teacher Impact Student Regulation in the Classroom? (Integrated)

In this final section, key findings from integrating the quantitative (code counts and time duration of regulation and activities structure) and qualitative (coded regulatory episodes) findings are presented. By examining findings from the two strands, a more complete understanding of how the teacher impacted student regulation in science classrooms was generated. Specifically,

1) Lesson Choices promote SRL and/or soRL
2) Active monitoring and intervening, by the teacher, ensure that students are behaviorally, cognitively, and affectively regulating
3) The teachers' approaches to directions, modeling, and questions influence SRL and/or soRL

Lesson Choices

The type of lesson structure and the activities the students participate in varied across classrooms and was related to the amount and type of regulation students exhibited. Across Teacher 3 and 4's classroom, the vast majority of the time was spent doing small group work (98% and 85% respectively). But given the collaborative nature of the experiments in Teacher 3's classroom, the students in this classroom exhibited the highest percentage of soRL (67%) and noticeably more regulation time than Teacher 4's classroom (68% compared to 45%). When examining how the students were working independently and interacting with one another during the experiments (Teacher 3's classroom) and science stations (Teacher 4's classroom), students were observed discussing what they were doing and seeing [*progress monitoring; affective reactions*] with their peers and teacher, even if each of them was working independently on their own experimental trials. They also worked together on one set of data analyses on the computer, further facilitating soRL [*evaluative learning outcomes*]. When working through the lab stations, some students did choose to work together on the questions, but more often students worked independently on the same questions and asked the teacher for help when they needed it [*seeking social assistance*].

Another example of how lesson choice dictated regulatory opportunities was observed in Teacher 2's classroom. The entire class period was kept in a whole class format, with the teacher guiding conversation and extremely limited peer interaction. The lowest percentage of total regulation seen during the class time (41%), and of that, virtually all were seen as student SRL (91%). The students' SRL was largely cognitive in nature, as the teacher was eliciting student ideas and asking them follow-up questions. This allowed them to justify their ideas [*relating to prior knowledge*] and verbalize their thought processes [*evaluating learning progress*].

Balancing Monitoring and Intervening

Teachers should be aware of what is going on in their classroom and be present for when their students need assistance, but there are benefits in giving students time to work without intervening. In particular, this delay allows students the time and space to begin their own work [*SRL*] and work with their peers [*soRL*].

One example of this involves Teacher 5 and her students working on their small group or individual research and poster projects. After giving explicit directions to students about how to complete their projects, she sat at her desk and attended to work there for about four minutes. During this time, students gathered in their groups [*environmental structuring*], got the materials required for their posters [*planning*], and began working. This gave the groups time to begin discussing their plans for completing the work collaboratively [*SSRL*]. This is contrasted with moments involving Teachers 1 and 4 in which they immediately begin going around the room, asking students how they are doing. In these classrooms, students began asking the teachers questions [*seeking social assistance*]. This often enabled the student to work by themselves [*SRL*], but not discuss plans and ideas with their peers.

The last case that highlights the importance of giving students spaces to have soRL moments is in Teacher 3's classroom. Teacher 3 is constantly observing the students working on their experiments, but only checks in with each pair of students 2-3 times in the class period. This occurred because she would be helping one of the other student pairs or she would be near the supply table or front of the room, monitoring students as they worked. From this, students were given a lot of time to work together and this classroom had by far the most instances of socially shared regulated learning by students (*SSRL;* $n = 14$). In these conversations, students were discussing their observations from the experiment [*comprehension monitoring*] and how they were going to graph their data [*planning*].

Directions, Modeling, and Questions

In addition to lesson choices and choosing when to intervene, how teachers verbally framed an activity and the types of questions they asked students during the activity played a part in the regulatory behaviors of the students.

Directions and Modeling Promote Student Regulation. Explicit directions and modeling are an important part of teacher pedagogy in science classes. They ensure the students will set up demonstrations, experiments, and projects correctly to be able to interact with science phenomena, but they are also associated with promoting students' regulation. Several teachers gave explicit instructions before small group activities began. The most noteworthy was Teacher 6 explaining to students how they were going to set up their lamps and manipulate their globes to be able to simulate the seasons of the Earth [*exploring task*]. If this was not done properly [*behavioral monitoring*], students would not be able to demonstrate the seasons and answer the questions on their worksheets. Teacher 6 showed them using a set of materials how they were going to set up their Sun-Earth systems and where all the supplies were on their tables [*exploring task demands*]. With minimal help from the teacher, the students were able to demonstrate the seasons and begin to answer conceptual questions and diagrams on their worksheets [*behavioral monitoring; making notes*]. This successful science demonstration allowed students to demonstrate their SRL through their actions in the activity [*behavioral monitoring*] and answering the questions [*comprehension monitoring; interim checking*]. In Teacher 6's classroom, the most instances of student SRL were documented (n = 60).

Teacher 1 also gave directions and modeled an SRL activity for the students. When they were working on their vocabulary individually, the students were asked to put an “X” by any words they can’t define without looking up and a checkmark by words they can define without looking up [*evaluating learning outcomes*]. This helped students evaluate their comprehension. Furthermore, the words with an “X”, the students were told to look up definitions to that word and rewrite the definition in 3-5 words, helping them summarize and paraphrase the definitions [*paraphrasing*]. This is when most of the SRL is demonstrated in the class.

Questions. Across the six classrooms, teachers asked a total of 789 questions throughout the 361 minutes of classroom video observations, more than two questions per minute on average. The following section categorized questions for the types of regulatory behaviors they elicit and their biggest positive effects on regulation in the classroom.

When coding teacher behaviors and student regulatory actions, two broad categories of teacher questions began to emerge, guiding and probing questions. Examples of guiding questions are, “What are you doing over here?” “What season comes after fall?” and “How are you going to get the water on the penny?” Often the teacher saw incorrect behavior or answers and asked the students questions to allow the student an opportunity to reflect and guide them to the correct behavior or answers [*evaluating learning progress; correcting errors*]. Examples of probing questions were, “What makes you think that?” “What does equinox sound like?” and “Why do we experience seasons?” These questions elicit student thinking, stimulating cognition and comprehension monitoring [*evaluating learning outcomes; comprehension monitoring*]. Guiding questions tended to have student behavioral regulation and correcting errors outcomes and probing questions tended to have cognitive regulation and comprehension monitoring outcomes.

Questions posed by the teacher help students' regulatory processes. In several classes, students were in the *performance phase* of regulation for extended periods of time (up to 50 minutes). Teacher questions helped students who were struggling with progress throughout the extended periods of performance. For example, when students forgot the next step in the science activity and what to complete next for classwork, teachers would assist them with a series of questions. First, would typically be a question to assess where the student is in the activity ("How many trials have you completed so far?"). This elicited *progress monitoring* in the performance phase of SRL. It was often followed by asking, "How many trials are you supposed to complete?", eliciting *evaluating learning progress* in the reflection phase of SRL. Lastly, the teacher ended with, "What are you going to do next?" which stimulated student *planning* in the forethought phase. While the larger class often flowed from forethought to performance to reflection from beginning to end, we would see teachers stimulate these smaller cycles within the overall performance phase of the class period.

Discussion

The purpose of this mixed methods case study was to better understand the ways student SRL and soRL manifest in middle school science classrooms in situ and how the teacher interacts with and influences this regulation. The quantitative findings establish the presence and broad patterns of student SRL and soRL and how they associate with dialogue contexts (i.e., one-on-one, small group, whole class) and activity structures (i.e., individual, small group, whole class). The qualitative findings provide an in-depth look at how student SRL and soRL manifest across and within the six classrooms. The following section highlights key findings from the study, highlighting theoretical and methodological implications. Practical implications are discussed followed by study limitations and directions for future research.

Targets (Behavioral, Affective, Cognitive, Metacognitive, and Motivational) of Regulation

Two key patterns related to regulatory targets were identified: 1) students' behavioral and affective regulation is often addressed by the teacher and/or students before cognitive regulation and 2) motivational and metacognitive regulation are less present or visible in the classroom.

Addressing Behavioral and Affective Regulation Before Cognitive Regulation

The results of this study provide evidence that both students and teachers address behavioral and affective regulation before cognitive regulation. For example, when working on an independent research project [*self-regulated learning*], a student needed to gather the correct materials from a table near friends [*planning; behavioral monitoring*] and work through frustrations around not being able to find the correct information [*affective reactions*]. Addressing the behavioral component of SRL then allowed the student to outline their research [*making notes; comprehension monitoring*]. Additionally, during socially regulated learning in small groups, students needed to perform the scientific demonstration accurately [*behavioral monitoring*] and collaboratively [*affective monitoring*] in order to observe the scientific phenomenon of the Earth's seasons. Only after working together to make those observations could the students answer the content review questions [*comprehension monitoring*]. These results suggest that in order to process science content using "top-down" cognitive reasoning and sensemaking, behaviors and emotions need to first be addressed. This highlights the vital importance of behaviors and emotions in the classroom, which is interesting given they are typically viewed as "bottom-up" processes (Batun et al., 2007). These patterns are in line with prior research, with similarly aged students (Lobczkowski et al., 2020; Rogat & Linnenbrink-Garcia, 2011), which showed that students' cognitive regulation was supported by positive social interactions (e.g., calm speaking tones, agreeing quickly) that promote positive emotions

(Lobczkowski et al., 2020; Rogat & Linnenbrink-Garcia, 2011). Similarly, in a study that analyzed students' regulation in collaborative settings, Rogat and Linnenbrink-Garcia (2011) found that much of students' regulation was behavioral (e.g., following directions, dividing up tasks) and both effective behavioral monitoring and positive socioemotional interactions allowed collaborative groups to focus on important cognitive monitoring. Taken together, this study extends these findings to both self- and socially regulated learning in middle school science classrooms.

Lack of Metacognitive and Motivational Targets of Regulation

Motivational regulation was detected minimally in the data and metacognitive regulation was not detected at all. This finding does not align with the theoretical literature that conceptualizes self- and social-regulation as a highly motivational and metacognitive process (Hadwin et al., 2018; Zimmerman, 2002). Given that this study focuses on observable manifestations of regulation captured via videos, these results could be explained by the deeply internal nature of metacognition and motivation (Cleary & Zimmerman, 2013). That is, these targets of regulation (motivation, metacognition) are not always readily observable in classroom videos and must be measured through surveys or think alouds. For example, the middle school students may not have been verbalizing or displaying these targets of regulation in observable ways (e.g., silent processing of information and application of strategies). This disconnect between theory and our results implies that more work including additional data sources to capture internal processes (e.g., surveys, interviews, think alouds) should be done to attempt to better understand students' motivational and metacognitive regulation in middle school science classrooms that cannot be observed in videos.

Phases of Regulation (Forethought, Performance, Reflection)

Two key patterns emerge when analyzing the cyclical phases of regulation (i.e., forethought, performance, and reflection; Zimmerman, 2002). They include: 1) The variation in time students spent regulating in each phase, with most time being in the performance (versus the forethought and reflection); and 2) Teachers facilitated multiple cycles of the regulation phases when students got stuck in the performance phase.

Predominance of the Performance Phase and Lack of Forethought and Reflection

Our findings support the idea that students' regulation during a classroom activity occurs within the performance phase, with less student regulation occurring during forethought and reflection. To elaborate, the majority of student regulation occurring in the performance phase included students employing elaboration strategies, such as *making notes* and *relating to prior knowledge*, monitoring strategies, such as *progress monitoring*, *comprehension monitoring*, and *behavior monitoring*, and refining strategy use, such as *seeking social assistance* and *environmental structuring*. Related to the predominance of the performance phase, there was a lack of students regulating in the forethought and reflection phases. In the science classrooms, students were regulating in the forethought phase by choosing the appropriate materials for their experiments [*planning*] and in the reflection phase by telling the teacher their progress throughout the experiment [*evaluating learning progress*].

These results are consistent with Quackenbush and Bol's (2020) study that found middle school students most frequently engaged in regulation during the performance phase of classroom math activities and less frequently in the forethought and reflection phases. These point to similarities between math and science classroom instructional practices. In both math and science, students practicing and performing scientific and mathematical tasks is critical for learning and as such teachers plan activities thoughtfully that engage the students largely in the performance phase of a task (Quackenbush & Bol, 2020). Specifically, teachers will often center their lesson plans around allowing the students to practice their science knowledge, observe science phenomena through demonstrations and experiments, and engage in scientific discourse. Additionally, the teacher's prompt for monitoring the accuracy of student task completion is important for the efficacy of the activity and in turn, will increase the amount of regulation students complete in the performance phase. It also can be posited that the teacher assumes a large part of the planning during a learning activity, but that this careful planning allows for the students to engage in high-quality performance regulation. For example, in order for the students to accurately complete a demonstration modeling Earth's seasons or their own controlled experiments, teachers needed to provide clear directions, model what behavior should look like, and have all materials easily accessible, all which require a great deal of planning on the teachers' part. This is in line with past studies in middle school math or science classrooms that showed that student metacognition is supported by teacher directions, modeling and prompting (Quackenbush & Bol, 2020; Zepeda et al., 2019). However, this extends our current understanding of student regulation by showing this is not supporting metacognition across all three phases, but specifically supporting regulation in the performance phase.

Short Cycles of Regulation Prompted by the Teacher

During an instructional activity, the following progression of regulation is often observed: the forethought phase at the beginning of activity, the performance phase occurring in the middle, and the reflection phase at the end of the activity (e.g., planning an experiment, conducting and recording data from multiple trials, and drawing conclusions from data analysis). This reflection would then influence the next forethought phase (Zimmerman, 2002). However, our study revealed an interesting finding that deviates from this theoretical understanding of the cyclical model of regulation. Our results showed that while the students were engaging in the performance phase, the teacher would prompt a short cycle of reflecting, planning out the students' next steps, before returning back to the performance phase. In practice, this was observed by a teacher coming over to help an individual student or a small group of students when the student(s) were stuck on a concept or procedure. The teacher would ask probing questions to have the students verbally reflect on their progress thus far [*evaluating learning progress; evaluating learning outcome*]. The teacher would then guide the student(s) through a new plan in order to continue to complete the activity [*planning*]. This would then help the student successfully regulate in the performance phase once again. These results highlight the importance of the teacher of teacher monitoring and prompts in supporting student regulation, which is supported in the literature (Quackenbush & Bol, 2020; Zepeda et al., 2019). These studies, conducted with similarly aged students, documented that teachers employ instructional strategies to promote student monitoring behaviors (Quackenbush & Bol, 2020) and that prompts, specifically in the form of questions, are the most common way teachers support their students' metacognition (Zepeda et al., 2019). In summary, this novel documentation of the cyclical phases of regulation points to the crucial role teachers have in supporting their students' regulation in situ.

Regulation in Middle School Science Classroom Contexts: The Crucial Role of the Teacher as Facilitator of Students' Regulation

The purpose of this study was to show how student self- and socially-regulated learning presents in middle school science classrooms and what impact the classroom teacher has on that regulation. A key takeaway is the teacher supports student SRL and soRL by planning and implementing high quality science activities.

Planning Inquiry-based, Collaborative Science Activities Supports SRL/soSRL

This study highlights ways SRL and soRL are exhibited in science classrooms. For example, Teacher 3 had her students engaging in an inquiry activity by openly investigating the effects of their chosen independent variable. These students were seen strategically picking out materials and designing experiment procedures [*planning*], carefully monitoring multiple trials [*progress monitoring, interim checking*], and writing up the results of their experiments [*evaluating learning outcomes*]. This inquiry-based science activity was thoughtfully planned by the teacher, given she chose four options of experiments the students could choose and provided them with the lab report outline to act as a scaffold throughout the experiment. It also provided the students with the opportunity to collaborate and not surprisingly, the students in this classroom exhibited the most soRL (n = 59). This result is in line with other studies documenting soRL during collaborative math (Rogat & Linnenbrink-Garcia, 2011; Quackenbush & Bol, 2020) and science (Lobczkowski et al., 2020; Nieswandt et al., 2020; Ucan & Webb, 2015) activities.

There was also evidence of fostering student SRL during inquiry-based science activities. For example, Teacher 6 allowed her students time to independently process scientific phenomena (i.e., the Earth's seasons) after a demonstration (i.e., the varying amount of sunlight cast on the Earth due to its revolution and tilted axis). The students answered questions [*paraphrasing*] and drew models [*making notes*] in their notebooks, while also asking the teacher for help [*seeking social assistance*] and asking for a quiet place to work [*environmental structuring*]. However, it is important to note that this activity took careful planning on the part of the teacher. The teacher had the materials and directions for the demonstration for the students to complete, had the questions prepared for the students to answer in order to process the phenomena they observed, and had a structure for students to easily work independently in their science notebooks.

Unsurprisingly, there was a concentration of SRL behaviors during this activity, and overall, this class had the highest amount of student SRL ($n = 60$). This is in line with prior literature that shows students exhibit SRL behaviors when they observe and discuss scientific phenomena and models (Patall et al., 2018; Nieswandt et al., 2020). This study expands on these ideas by highlighting how teachers plan science activities that promote soRL in addition to the previously established student SRL

Implementing Science Activities Supports More Cognitive SRL/soRL

This study also shows that teachers' classroom instruction can influence student cognitive SRL and soRL. Specifically, this study documented how cognitive SRL and soRL was more often initiated by the teacher than initiated by the individual student or peers. The teacher guides the student(s) to identify and correct their misconceptions by initiating with them in co-regulation. For example, as the teacher was actively monitoring, they looked at a student's worksheet and asked the student "so what is giving you trouble?" The student replied, "I don't get how to graph this" [*comprehension monitoring*]. This helped the student monitor and advance their understanding of dependent and independent variables and how to graph them. In contrast, student-initiated or led moments of SRL, coRL, or SSRL typically were more often behavioral or task oriented (e.g., how to set up the experiment, splitting up tasks for a project, asking for materials). Taken together, this identifies the teacher as a crucial co-regulator in the classroom.

This focus on the teacher as a co-regulator expands existing literature that focus primarily on student-led soRL (Lobczkowski et al., 2020; Nieswandt et al., 2020; Ucan & Webb, 2015). For example, Lobczkowski and colleagues (2020) examined the relationships among high school students' socially regulated learning, socioemotional reactions, and engagement in scientific discourse and showed that soRL helped students engage in scientific discourse, difficult content often placed a strain on student regulation, and teachers' support changed student regulation. Although the role of teacher emerged as an important part of students' regulation, the teacher was considered external. Extant literature often characterizes the teacher as an external regulator, given that the scope of their work is squarely focused on student collaboration and soRL. This study expands that scope to include the teacher as a key member of students' co-regulation, contributing contemporary scholarship on soRL (e.g., Lobczkowski et al., 2020; Nieswandt et al., 2020; Ucan & Webb, 2015). There are also several recent studies establishing the relationship between teachers' actions and student SRL (Dignath and Veenman, 2020; Perry et al., 2020; Zepeda et al., 2019). Those studies documented that teachers impact SRL by modeling and prompting (Zepeda et al., 2019), direct and indirect learning strategies (Dignath & Veenman, 2020), and through clear directions and student choice (Perry et al., 2020). Our findings align with results from both the SRL and soRL literature bases. By focusing on the teacher's role in supporting both students' SRL and soRL in science classrooms, this study draws together what we know about student SRL and soRL and the key role of the classroom teacher.

Implications for Theory and Research

This study contributes to our understanding of regulation frameworks by highlighting 1) the co-manifestations of different phases and targets of regulation, 2) the importance of behavioral regulation for all other targets of regulation, and 3) concrete examples of the interplay between SRL and soRL in science classrooms.

Co-manifestations of Different Phases and Targets of Regulation

Much of the literature surrounding SRL and soRL is highly cognitive and motivational in nature. Most commonly, SRL studies adopt or adapt Zimmerman's (2002) cyclical model as their guiding theoretical framework (Cabrera et al, in preparation; Panadero et al., 2015). This model incorporates three phases of regulation (forethought, performance, and reflection) with cognitive (e.g., relating to prior knowledge) and motivational (e.g., positive self-talk) targets of regulation. However, this study extends this work by systematically documenting how several targets (e.g., motivational, cognitive, behavioral, emotional, and metacognitive) of both SRL and soRL manifest in different phases (e.g., forethought, performance, reflection) of regulation. Conceptualizing student regulation in a more complete way can be valuable for theory development as well as considering the affordances and weaknesses of different methods to study SRL and soRL. For example, although the classroom video coding approach used in this study allowed us to capture various components of SRL and soRL in real time (addressing a notable weakness of common self-report measures and/or lab-based think alouds), it may not be the best approach for capturing more internalized processes such as non-verbal metacognitive strategies. A comprehensive framework of all of the phases and targets of regulation allows us to systematically identify the best methods to examine and understand the complex regulation processes that occur in the classroom across contexts.

The Undervalued Target of Behavioral Regulation

A notable finding of this study is the disconnect present between the minimal focus on behavioral regulation in the literature and the abundance of behavioral SRL and soRL present in this study. Findings from this study show that many of the other regulatory processes necessary to successfully engage in the science activities were contingent on behavioral regulation. That is, behavioral regulation can be seen as a gatekeeper for more sophisticated targets of regulation (e.g., cognitive, motivation). Specifically, this study reveals that simply doing the correct, or on-task behavior helped enable learners to observe scientific phenomena and allowed for the teacher to help engage in deeper thinking. It also showed how teachers will often focus on making sure students are regulating their behaviors (e.g., having the right materials, staying at their workstation) first before engaging with students about the content (e.g., grappling with misconceptions, correcting errors, connecting to prior knowledge). This study suggests that targeting behaviors is important for unlocking the ability to target more taxing cognitive and metacognitive tasks.

Evidence of the Interplay Between Self-Regulated Learning and Socially Regulated Learning

Additionally, the interplay between SRL and soRL has been theorized in recent work but empirical work examining these relationships is lacking. In a single class period, students and teachers move between small group, individual, and whole class learning, which lend themselves to either SRL or soRL (i.e., students will use SRL during individual work and soRL during small group activities). However, by coding SRL and soRL simultaneously, unique patterns emerged.

There was a common pattern of acts of SRL preceding acts of soRL. For example, the teacher supported SRL by correcting one student's understanding of the science content [*SRL*], followed by addressing the whole class, ensuring all students are activating their prior knowledge [*coRL*]. The reverse order was also observed, in which SRL emerged from soRL. For example, when a student is seen using a learning strategy [*SRL*] that the teacher went over with them earlier in the class period [*coRL*]. This is empirical evidence of the internalization after co-regulation in episodes of subsequent SRL, usually just discussed theoretically. This systematic documentation is consistent with and contextualizes the theoretical relationship between SRL and soRL (Hadwin et al., 2018).

Comprehensive SRL and soRL Framework and Coding Scheme

This study contributes to the ways in which researchers can study SRL and soRL. The integrated and comprehensive framework and coding scheme presents a novel approach to regulation research that allows researchers to capture moments of SRL and soRL, various phases of regulation, and different targets of regulation. This coding scheme helps to show the fluid nature in which students exhibit their regulation (i.e., emotional regulation shifting to cognitive regulation).

Practical Implications

This study shows that teachers impact student SRL and soRL through their pre-planned and moment-to-moment pedagogical choices and actions. Pre-planned choices such as seating arrangements, lesson activity structures, and guided demonstrations and experiments all influence the amount and type of regulation students exhibited in classroom settings. By recognizing how these choices can impact student regulation in the classroom, teachers can proactively promote positive SRL and soRL behaviors (e.g., have furniture arranged in clusters for group work, establishing clear routines early in the school year). Further, the following moment-to-moment actions were also shown to facilitate student regulation: asking probing and guided questions, writing and stating directions explicitly, and active monitoring. Teachers can be made more aware of how these everyday actions can help their students regulate their learning independently (SRL) and in collaborative groups (soRL).

Additionally, this study shows the importance of regulating behaviors and emotions (in addition to cognition) in the science classroom for safely and authentically conducting demonstration, and experiments. Findings from this study underscored the importance of behavioral regulation (e.g., using lab materials properly) to facilitate more advanced forms of self and co-regulation in science classrooms such as relating to prior knowledge and comprehension monitoring. In contemporary literature, SRL studies tend to focus on higher-order forms of regulation, such as cognitive and motivational (Perry et al., 2020; Zepeda et al., 2019) and soRL studies focus on socioemotional and cognitive regulation (Lobczkowski et al., 2020; Nieswandt et al., 2020; Ucan & Webb, 2015). This study underscores the importance of behavioral and emotional regulation. This finding aligns with what many teachers inherently appreciate and understand in terms of the crucial importance of classroom management for creating a successful learning environment for their students' learning, established by creating and establishing routines early in the school year. Findings from this study showed that when students were fluent in these rote science classroom routines (e.g., getting lab materials), they were able to sustain behavioral regulation (e.g., use a heat lamp safely) and more quickly engage in cognitive regulation (e.g., connecting Earth's tilted axis, revolution, and season).

Another important practical implication of this study is how features of the science learning activity can facilitate or deteriorate students' regulation and co-regulation processes. On a large scale, the physical layout and the furniture in the classroom impact student SRL and soRL. Furnishings and seat arrangements in which students are isolated or all facing the same direction (e.g., towards the front board) help foster SRL and inhibit soRL. Oppositely, furnishings and layouts in which students are clustered and can face each other promote soRL. Moveable furnishing that can be rearranged for the purpose of the activity can allow for the flexibility needed to promote SRL or soRL (e.g., wanting students to collaborate on a project or desks that allow students to work by themselves). Additionally, the length of time spent on an activity impacted students' regulation. There is evidence that teachers should design lessons that are long enough to elicit cognitive regulation, but not too long where behavioral and emotional regulation begin to deteriorate. It took time for students to begin the learning activity and get settled with the materials before they could start interacting with the science content, therefore, very short activities will focus on behavioral regulation instead of the "top-down", cognitive regulation. However, behavioral and emotional regulation was negatively affected during long class activities. For example, during long, whole class discussions, students began getting distracted and even falling out of their seats. Also, during longer small group activities, students began having off-task conversations and even began having arguments. Taken together, this points to the importance of being intentional with the length of classroom activities when planning lessons.

Lastly, this study examined several contextual features of the classroom environment (in tandem with teacher moves) that supports students' regulation in turn, likely supporting students' agency over their learning. Regulation in the classroom is closely tied to student agency in that the ultimate goal is to shift ownership over how one learns to the student (Code, 2020; Oxford, 2016). This study contributes to the literature by highlighting these regulatory and potentially agentic student behaviors. We recognize that there are often opportunity gaps for historically underrepresented minority groups in science classes (Bae et al., 2018; Morgan et al., 2016; Quinn & Cooc, 2015). This study contributes to the literature by systematically documenting opportunities that were present in these urban classrooms. However, studies of science learning in urban contexts show that creating learning spaces that truly positions students as agents of their learning require structural, social, norm shifts (Garrin, 2014). While this study begins to examine regulation through the urban classroom lens, future work could further explore the complex, interpersonal dynamics of urban classroom interactions and how they affect student regulation.

Limitations and Directions for Future Research

This study is cross-sectional in nature, aiming to sample two classrooms for each grade level in middle school. However, this limited our data to only one class period per teacher. This limits the study in two ways. First, we only see a very small amount of the total interactions the teacher will have with these students. Secondly, we fail to see any changes over longer time-spans. To build stronger patterns of SRL and soRL in classrooms, more class periods for each teacher should be recorded and analyzed. This would be able to show more longitudinal changes of student regulation within each classroom. It also would provide more evidence on how specific teacher choices affect student regulation within their classrooms, by looking at more data between each classroom case. This would further highlight differences between teachers' choices and behaviors that affect student regulation.

This study also looks at science classrooms exclusively, aiming to identify domain-specific ways students regulate in science classrooms. While some domain specific conclusions were made, future studies could collect data on students in different subjects and compare across domains. This would help compare and contrast how students' regulation is similar and different across domains. It would also help show if there are domain specific classroom activities that aid in regulation development.

Also, this study does not focus on the sociocultural complexities of an urban classroom. Given our sample includes urban classrooms, future research would benefit from not only looking at high-quality science activities, but those activities that are equity-focused (e.g., incorporating students' funds of knowledge, students' sense of belonging and agency; Bae et al., 2022). Focusing on equity-focused pedagogy would provide additional insight into socially-regulated learning, as relationships between peers and the teacher can influence soRL (Lobczkowski et al., 2020; Rogat & Linnenbrink-Garcia, 2011).

Lastly, this study shows mostly overt, or observable, manifestations of regulation and lacks additional data such as surveys and interviews that would capture covert, or unobservable, manifestations of regulation. Given much of regulation, especially metacognitive and motivational targets of regulation are covert, future studies that incorporate surveys and interviews into the research design, would help expand on the student regulation findings presented by this study. Further, incorporating teacher surveys or interviews would give teachers the opportunity to explain why they made certain classroom and instructional choices and actions and how they perceived their students' regulation.

Conclusion

The modern-day science classroom is filled with dynamic elements that require student self- and social regulation in order to learn. This regulation can be stimulated and effected by the teachers' predetermined choices surrounding their classroom environment and lessons, as well as their pedagogical actions when carrying out those lessons.

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