UNCERTAINTY AND SOCIAL REGULATION OF LEARNING IN COLLABORATIVE INQUIRY AND DESIGN TASKS IN SCIENCE

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A dissertation submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements of the degree of Doctor of Philosophy in the School of Education (Learning Sciences and Psychological Studies).

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ABSTRACT

Dalila Dragnić-Cindrić: Uncertainty and Social Regulation of Learning in Collaborative Inquiry and Design Tasks in Science
(Under the direction of Jeffrey A. Greene)

Learners need to develop multifaceted skills and knowledge in order to productively engage with today’s increasingly uncertain world. To this aim, science educators strive to build students’ science knowledge by engaging them in scientific practices, such as collaborative inquiry, which are social and collaborative in nature. However, learners continue to experience various challenges related to collaborative inquiry. In science, one such domain-specific challenge is uncertainty, which is inherently present in science inquiry. Yet, there have been no studies illuminating how science learners jointly manage the uncertainty encountered in collaborative inquiry.

In this multimethod study, I explored how groups of preservice elementary school teachers in a science methods course regulated their learning in response to uncertainty in collaborative inquiry and design tasks. I assigned participants to groups based on their individual uncertainty orientations. I video-recorded three groups (N = 12): an uncertainty-oriented group, a certainty-oriented group, and a group of mixed uncertainty orientations, in a series of five collaborative inquiry tasks of varying uncertainty levels. Using quantitative analysis of the coded data and qualitative analysis of the video observations, I determined three salient cross-cutting themes (i.e., collaborative work, regulative processing focused on task, and use of social-comparison in regulation of learning) across the groups, as well as three themes unique for each
group (e.g., active pursuit of uncertainty for the uncertainty-oriented group, the avoidance of uncertainty for certainty-oriented group, being untroubled by uncertainty for the mixed group), totaling nine themes that described their social regulation of learning. Findings from this study contribute to the knowledge on social regulation of learning in science, science education, and social psychology. I suggest potential directions for future research, including discerning and contextualizing adaptive and maladaptive use of social comparison in social regulation of learning and illuminating the role of group members’ uncertainty orientations in group leadership.
To Goran and Alen, my Suns.

To my family, killed during the siege of Sarajevo.

“We demand rigidly defined areas of doubt and uncertainty!”
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<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>CO</td>
<td>Certainty-oriented</td>
</tr>
<tr>
<td>CoRL</td>
<td>Co-regulated learning</td>
</tr>
<tr>
<td>SSMR</td>
<td>Socially-shared metacognitive regulation</td>
</tr>
<tr>
<td>SSRL</td>
<td>Socially-shared regulation of learning</td>
</tr>
<tr>
<td>SRL</td>
<td>Self-regulated learning</td>
</tr>
<tr>
<td>UO</td>
<td>Uncertainty-oriented</td>
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CHAPTER 1: INTRODUCTION

Students entering elementary classrooms today will be young adults in 2030, and these adults will need to apply their knowledge and adaptive abilities in a world characterized by pervasive uncertainty and increasingly complex social, environmental, and economic challenges (The Organisation for Economic Co-operation and Development [OECD], 2018). There is a consensus that active and responsible participation in the global “innovation- and knowledge-based economy” (Sawyer, 2014, p. 729), necessitates multifaceted competencies (Graesser et al., 2018; Hesse, Care, Buder, Sassenberg, & Griffin, 2015; Järvenoja, Järvelä, & Malmberg, 2015; OECD, 2018; Scardamalia & Bereiter, 2014). These new competencies include the scientific and technological literacy needed to understand and address complex and ill-structured challenges of the 21st century (National Research Council [NRC], 2012), as well as the coveted skills known as “the Four Cs” (i.e., collaboration, communication, critical thinking, and creativity; National Education Association, 2014). However, on a recent nationwide science assessment, around 62 percent of American fourth-graders and around 66 percent of eighth-graders performed below proficient level as defined by the National Assessment of Educational Progress (NAEP; NAEP, 2015). In the same assessment year, 78 percent of twelfth-graders performed below NAEP proficient level in science (NAEP, 2015). These data suggest that the science acumen of K-12 students, one of the key building blocks for successful participation in modern society, is not on par with the challenges they are likely to face as young adults.
The authors of the most recent science education standards document, the Next Generation Science Standards: For States, By States (NGSS; NGSS Lead States, 2013) aimed to holistically address students’ under-preparedness by focusing educators on concurrently developing students’ scientific knowledge and practices. According to the NGSS, quality science education necessitates integration of following three dimensions: (a) science and engineering practices; (b) cross-cutting concepts, which have applications across fields of science and engineering, and; (c) core disciplinary ideas in four areas (i.e., physical, life, earth and space sciences; and engineering, technology, and applications of science; see Appendix A for details). The NGSS authors outlined eight essential scientific and engineering practices for modern K-12 science and engineering education: (a) asking questions and defining problems; (b) developing and using models; (c) planning and carrying out investigations; (d) analyzing and interpreting data; (e) using mathematics and computational thinking; (f) constructing explanations and designing solutions; (g) engaging in argument from evidence; and (h) obtaining, evaluating, and communicating information. The NGSS authors gave a new prominence to the understanding of science as a social practice (NGSS Lead States, 2013). Furtak and Penuel (2019) pointed out that the new emphasis on scientific practices constitutes a change in science education; in other words, a “practice turn” (p. 171).

Previous reform and standards documents (e.g., NRC 1996, 2000) were characterized by a focus on inquiry, defined as:

a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations. (NRC, 1996, p. 23)
Moreover, the NRC writers specified that inquiry means both the individual and group “activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world” (NRC, 1996, p. 23). However, in practice, the inquiry focus expressed by the NRC authors was often translated by practitioners into superficial engagement of students in individual or group step-by-step, cookbook-like activities, which did not help students learn about what is unique to the thinking and acting of practicing scientists (Ford, 2015; Furtak & Penuel, 2019). The authors of the NGSS clarified that inquiry in science includes direct participation in a range of “cognitive, social, and physical practices” (NGSS Lead States, 2013, p. xv) and foregrounded collaborative inquiry as a hallmark of effective science teaching and learning. Three-dimensional science instruction, aligned with the NGSS, means that students engage in science and engineering practices, which are social and collaborative in nature, to study and apply crosscutting concepts to develop understanding of the key disciplinary ideas (NGSS Lead States, 2013). Thus, to meet this ideal of science education for the current century, K-12 science teachers need to engage and support their students’ participation in authentic and interconnected science and engineering practices through effective collaborative inquiry.

**Collaborative Inquiry in Science**

Empirical studies have shown that students who participated in well-designed and implemented inquiry-based science learning interventions that aligned with the NRC’s definition of inquiry had higher knowledge gains than students in comparison groups that engaged in regular classroom learning (Johnson-Glenberg, Birchfield, Tolentino, & Koziupa, 2014; J. C. Marshall & Alston, 2014; J. C. Marshall, Smart, & Alston, 2017; Marx et al., 2004). Moreover, inquiry-based science learning has shown promise for reducing achievement gaps in science
between urban minority boys and girls (Geier et al., 2008) and minority students relative to Caucasian students (J. C. Marshall & Alston, 2014). However, collaborative inquiry in science, where investigations are carried out by small-groups, remains challenging for teachers (Capps & Crawford, 2013; Capps, Shemwell, & Young, 2016; Holbrook & Kolodner, 2000; Marx, Blumenfeld, Krajcik, & Soloway, 1997; D. Z. Meyer, Antink Meyer, Nabb, Connell, & Avery, 2013) and students (Krajcik et al., 1998; Sinha, Rogat, Adams-Wiggins, & Hmelo-Silver, 2015; Veermans & Järvelä, 2004; Woods-McConney, Wosnitza, & Sturrock, 2016). In this study, I propose to investigate why teachers and students struggle with successful implementation of and learning through collaborative inquiry in science.

Science education researchers have repeatedly found that teachers struggle to shift away from traditional, teacher-centered instruction and evolve their pedagogical practice toward inquiry-based teaching, which, according to the NRC definition, might include individual or group investigations (e.g., Capps & Crawford, 2013; Capps et al., 2016; McNeill, Pimentel, & Strauss, 2013). In recent studies, science teachers self-reported high levels of inquiry-based teaching (Blanchard, Osborne, Wallwork, & Harris, 2013; Capps & Crawford, 2013; Capps et al., 2016) but a closer review revealed that their knowledge of science inquiry was not well-structured (Capps et al., 2016) and there was little evidence of inquiry in observations of these teachers’ practice (Capps & Crawford, 2013). These findings resonate with concerns expressed by Chinn and Malhotra (2002) who compared inquiry in K-12 science classrooms with the authentic inquiry done by real scientists and found that school-based inquiry led to students’ thinking that was simple, algorithmic, and certain as opposed to the goal of authentic scientific reasoning, which is characterized by complexity, creativity, and uncertainty.
Whereas in traditional teacher-led instruction teachers might approach classroom management and instruction as two separate tasks they need to attend to, a collaborative inquiry-based science classroom necessitates that teachers shift to complex and pervasive classroom management (Harris & Rooks, 2010). Pervasive classroom management means concurrently attending to the interconnected elements that are needed for productive and active student engagement in collaborative inquiry: (a) a tight-knit classroom community of science learners; (b) well-functioning collaborative groups of students; (c) interconnected science concepts and practices; (d) sustained task engagement; and (e) skillful adaption of the curricular materials (Harris & Rooks, 2010). Faced with the complexity of inquiry-based teaching and learning, which has been conceptualized to include both individual and group inquiry, researchers have found teachers often resort to reducing cognitive demands by attending to surface aspects of the inquiry (i.e., structured, step-by-step procedures) or product generation (e.g., Blumenfeld & Meece, 1988; Capps & Crawford, 2013) or by modifying collaborative inquiry by eliminating its key aspect: group work (Fogleman, McNeill, & Krajcik, 2011; Krajcik et al., 1998; McNeill et al., 2013). Such modifications amounted to “lethal mutations” (Brown & Campione, 1996, p. 292) to the curriculum, and have resulted in classroom practices focused on superficial activities that were disconnected from the scientific practices and intended learning goals of collaborative inquiry in science (McNeill et al., 2013).

NGSS (NGSS Lead States, 2013) emphasized a vision of science education in which students engaged in collaborative inquiry in science are active participants in scientific practices and knowledge construction, and work with peers to ask meaningful questions, draw on their previous knowledge as they think about complex science phenomena, plan and organize their investigations, analyze data, use existing and build new models, construct evidence based
explanations, and communicate their conclusions (Crawford, 2014; Krajcik et al., 1998; Marx et al., 2004). Bell, Urhahne, Schanze, and Ploetzner (2010) reviewed various models of collaborative-inquiry learning and determined that most theorists agree that participants in collaborative inquiry go through the following nine iterative processes: (a) orientation and asking questions; (b) generating hypotheses; (c) investigation and task planning; (d) investigating the phenomenon; (e) analyzing and interpreting data; (f) modeling; (g) predicting the outcomes; (h) finalizing results, generating conclusions, and evaluating findings; and (i) communicating with others. Bell and colleagues pointed out that collaborative groups do not enact these processes in a fixed, prescribed sequence but rather engage in them and re-visit them as needed during inquiry. Moreover, students need to sustain their interest, motivation, and positive group climate throughout the duration of their investigation to have successful learning outcomes (Krajcik et al., 1998; Marx et al., 2004; Ucan & Webb, 2015). Unfortunately, and perhaps unavoidably, learners in collaborative groups experience various challenges (e.g., motivational, socio-emotional, cognitive, etc.) as they work together to achieve their individual and group learning goals (Bakhtiar, Webster, & Hadwin, 2017; Barron, 2003; Järvelä, Järvenoja, Malmberg, & Hadwin, 2013; Järvelä, Volet, & Järvenoja, 2010; Näykki, Järvelä, Kirschner, & Järvenoja, 2014; Ucan, 2017). Even students engaged in well-designed collaborative inquiry in science encountered challenges such as ignoring their intellectual contributions (e.g., Krajcik et al., 1998; Woods-McConney et al., 2016), socio-emotional conflicts (e.g., Krajcik et al., 1998; Sinha et al., 2015), and refusals of some group members to work collaboratively (e.g., Sinha et al., 2015; Veermans & Järvelä, 2004; Woods-McConney et al., 2016). Hence, there is a need for research on collaborative inquiry struggles and the ways in which groups of learners might be able to avoid or overcome them.
Social Regulation of Learning

Researchers of socially-shared regulation of learning (SSRL) have focused on strategic and intentional planning, monitoring, controlling, and evaluating of cognition, metacognition, behavior, motivation, emotions and environment that small groups employ to prevent or adaptively respond to the challenges that take place during collaborative work (Hadwin, Järvelä, & Miller, 2018). SSRL research has its roots in research on self-regulated learning (SRL; Hadwin et al., 2018). SRL refers to the “ways that learners systemically activate and sustain their cognitions, motivations, behaviors, and affects toward the attainment of their goals” (Schunk & Greene, 2018, p. 1). SRL has three loosely ordered, recursive phases: before, during, and after learning (Greene, 2018; Zimmerman, 2013). As learners progress through the phases of SRL and work toward the completion of the learning task, their automated learning plans and strategies may prove insufficient for producing a successful learning outcome. Thus, learners might need to engage in effortful and intentional regulative processes to stay on track. Potential targets of these SRL processes include any aspect of learning that learners might think about and control (Greene, 2018). Greene (2018) emphasized there are six categories of targets of self-regulation: cognition, metacognition, behavior, motivation, affect, and external environment. Processes of SRL that learners may invoke over the course of learning include planning, monitoring, control and evaluation of learning (Greene, 2018). Whereas SRL researchers focus on individual learners, SSRL refers to the dynamic processes of groups’ joint “negotiated, iterative fine-tuning of cognitive, behavioral, motivational, and emotional conditions/states as needed” (Hadwin et al., 2018, p. 83).

Research findings have indicated that SSRL skills are pre-requisite and essential for successful collaborative learning (Hadwin et al., 2018; Järvelä & Hadwin, 2013; Järvelä et al.,
Learners engaged in collaborative interactions rely on three modes of regulation to overcome challenges: SRL, co-regulation (coRL), and SSRL (Hadwin, Järvelä, & Miller, 2011; Hadwin et al., 2018; Järvelä & Hadwin, 2013). SRL refers to each group members’ individual SRL. For example, a member of the group might realize that she is repeatedly distracted from the group’s task by her phone and decides to put it away in her bag. The other two modes of regulation, coRL and SSRL, are social in nature (Hadwin et al., 2018). CoRL refers to temporary and transitional support of one or more learners in the group by one or more other members in the regulative processes of strategic planning, monitoring, evaluating, or adapting with the aim of shifting the regulatory ownership to the “regulated” individuals (Hadwin et al., 2011; Hadwin et al., 2018). For example, one member of the group might prompt another member to focus attention on the task instead of chatting with the neighboring group. After several prompts, the regulated member might abandon side conversations and fully engage in group work, exercising self-control, and thus taking ownership of his or her regulative processes. SSRL refers to the group’s collective and egalitarian regulation of learning (Hadwin et al., 2018). For example, one member might suggest the group should develop a plan prior to tackling the learning task. Others in the group might reciprocate by contributing their ideas on how to create the plan and what to include in it. Hence, the group jointly works to discuss, evaluate, and integrate everyone’s ideas in their group’s plan. Social regulation of learning is an overarching term used to refer to SRL, coRL, and SSRL together (Hadwin et al., 2018).

Importantly, it is possible for learners’ regulative proficiency to improve over time. For example, researchers have found the frequency with which successful small-groups engaged in SRL and SSRL increased over a series of collaborative sessions (De Backer, Van Keer, &
Valcke, 2015; Grau & Whitebread, 2012; Ucan, 2017) and within individual collaborative sessions (Malmberg, Järvelä, & Järvenoja, 2017). Whereas the authors of these studies did not measure the groups’ learning outcomes, they did find that the groups that engaged more in SSRL attended more to the key aspects of the task goal and knowledge relevant to the task than the groups that employed coRL, who tended to focus on superficial aspects of the task (Grau & Whitebread, 2012). SSRL groups also showed increased engagement in deep content processing such as asking thought-provoking questions and providing knowledge-building explanations (De Backer et al., 2015). SSRL groups’ focus on key aspects of the task and utilization of deep content processing form a base for better learning outcomes (De Backer et al., 2015; Grau & Whitebread, 2012). So far, findings regarding the actual rates of coRL during collaboration have been mixed. Ucan (2017) found that the frequency of groups’ engagement in coRL fluctuated over the sequence of collaborative sessions with increasingly complex tasks, and had different patterns for different groups. Malmberg et al. (2017) found that coRL fluctuated within the individual collaborative sessions, emerging when group members, through monitoring, found it necessary to temporarily support others. These observations are consistent with findings that coRL serves to facilitate the emergence of SRL (DiDonato, 2013) and the collective and egalitarian form of regulation, SSRL (De Backer et al., 2015; Malmberg et al., 2017). Taken together these findings indicated that students’ improved SSRL ability is also a learning outcome that serves as a base for future collaborative learning. In science classrooms, collaborative inquiry is a cornerstone of science teaching and learning (NGSS Lead States, 2013). Thus, it is especially important that science teachers develop expertise for fostering their students’ SSRL and developing students’ SSRL proficiency necessary for productive engagement in collaborative inquiry in science. In this study, I intend to focus on phenomena that manifest
during group regulation of learning as well as domain-specific challenges, such as uncertainty in science, as one of the possible reasons why teachers and students struggle with collaborative inquiry in science.

**Social regulation of learning in science education.** However, despite the steady growth in the body of research on social regulation of learning over the past 10-15 years, SSRL studies in the domain of science education remain scarce. Several researchers (see Table 1) have focused on identification of modes of regulation (i.e., SRL, coRL, and SSRL), and their emergence and temporal development over multiple collaborative sessions (e.g., Grau & Whitebread, 2012; Ucan, 2017; Ucan & Webb, 2015). Typically, more successful collaborative inquiry groups are those that are able to enact all three modes of social regulation of learning when needed (Grau & Whitebread, 2012; Ucan, 2017; Ucan & Webb, 2015). Findings from these studies suggest that students need to engage in collaborative learning in science over prolonged periods of time in order to shift toward more egalitarian forms of regulation of learning (i.e., SSRL) and be able to activate their own SRL processes more often (Grau & Whitebread, 2012; Ucan, 2017).
Table 1

**SSRL Studies in Science Education**

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants (Country)</th>
<th>Group structure</th>
<th>Grade (Age)</th>
<th>Instructional topic/model</th>
<th>Task</th>
<th>No. of collaborative sessions</th>
<th>Research topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grau &amp; Whitebread (2012)</td>
<td>2 groups of 4 students (Chile)</td>
<td>Teacher formed; mixed gender and ability;</td>
<td>3rd (8-9 y.o)</td>
<td>Plants as producers; living things/Not specified</td>
<td>Codesigned w/ teacher More than one solution; Single common product from each session.</td>
<td>5 over the course of the semester (March-July)</td>
<td>Comparison of SSRL vs. CoRL.</td>
</tr>
<tr>
<td>Kosha &amp; Volet (2014)</td>
<td>2 groups of 5-6 students (not specified)</td>
<td>Self-formed; Similar previous AA</td>
<td>2nd-year veterinary medicine undergraduates</td>
<td>Physiology / clinical case-based collaborative learning</td>
<td>Generation of the learning objectives for the case and construction of a concept map; No time limit.</td>
<td>3 for Task 1 and 1 for Task 2 over 6-7 week period</td>
<td>Impact of groups’ cognitive activity and SSMR on different learning outcomes.</td>
</tr>
<tr>
<td>Iiskala et al. (2015)</td>
<td>1 group of 4 students (Finland)</td>
<td>Above average AA</td>
<td>7th</td>
<td>Universe/Asynchronous CSCL</td>
<td>5 phase inquiry starting with student chosen ill-defined question.</td>
<td>18</td>
<td>SSMR.</td>
</tr>
<tr>
<td>Ucan &amp; Webb (2015)</td>
<td>2 groups of 3 students (Turkey)</td>
<td>Self-formed; Mixed gender and previous science AA; Good collaboration skills</td>
<td>7th (12 y.o.)</td>
<td>Human body systems / Not specified</td>
<td>Related to students’ daily lives, promoting more than one viewpoint, increasing difficulty; whole class sessions after each coll. session.</td>
<td>5 over the course of the 7 week long unit that included 17 lessons</td>
<td>Social forms of metacognitive, emotional and motivational regulation processes and impact on collaborative inquiry.</td>
</tr>
<tr>
<td>Grau &amp; Whitebread (2012)</td>
<td>2 groups of 4 students (Chile)</td>
<td>Teacher formed; mixed gender and ability;</td>
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<td>Comparison of SSRL vs. CoRL.</td>
</tr>
</tbody>
</table>

*Note.* AA = academic achievement; y.o. = years old; SRL = self-regulated learning; coRL = co-regulated learning; SSRL = socially-shared regulated learning; SSMR = social-shared metacognitive regulation.
Other researchers (e.g., Iiskala, Volet, Lehtinen, & Vauras, 2015; Khosa & Volet, 2014) have devoted attention to an aspect of SSRL called socially-shared metacognitive regulation (SSMR), which includes collective group processes of task planning, monitoring, evaluating and adapting. Groups that engaged in higher-level metacognitive regulation processes related to the fundamental aspects of the task (e.g., attending to task goals) as well as in higher-level cognitive activities (e.g., elaboration and justification of content) had better performance outcomes on complex science tasks than groups that focused on superficial issues of the task (e.g., trivial details about drawing and coloring) or simple fact gathering (Grau & Whitebread, 2012; Khosa & Volet, 2014). Successful groups monitored their metacognition and changed the direction of the group’s inquiry when the group members perceived it to be inadequate (Iiskala et al., 2015; Ucan & Webb, 2015).

In addition to metacognition, SSRL regulative targets include cognition, behavior, external environment, emotions, and motivation. Ucan (2017) observed that students engaged in regulation of their emotions and motivation more often as the learning tasks became more complex. The author speculated the increasingly complex group tasks might have led to more negative emotions among group members or low levels of motivation, thus necessitating regulative engagement to overcome experienced challenges. Group members also likely felt increasingly comfortable with their peers, and were more open about their negative feelings, trusting that the group could work together to overcome them. Ucan concluded that SSRL may be especially necessary and beneficial as science learning tasks get more complex, and students need to regulate their emotions and motivation more often.

Ucan (2017) and Ucan and Webb (2015) found that groups of science learners who started with strong social bonds were particularly successful in sharing responsibility for
regulating groups’ emotions and motivation. Their findings are consistent with findings from the broader SSRL literature. Members of successful groups shared the perception at the task onset that they are collectively rather than individually responsible for group regulative processes, thus setting up conditions for a positive collaborative engagement, starting with task planning (Bakhtiar et al., 2017; Rogat & Linnenbrink-Garcia, 2011). Positive affect and positive group interactions cyclically support each other, leading to a positive group climate (Bakhtiar et al., 2017; Linnenbrink-Garcia, Rogat, & Koskey, 2011; Rogat & Linnenbrink-Garcia, 2011). Successful groups also showed commitment to the group’s success through jointly regulating emotions when they faced an emotional challenge to prevent conflict and restore positive climate (Järvenoja & Järvelä, 2013). Groups’ collective regulation of emotions and motivation is likely to play an important role in collaborative inquiry in science where groups of learners are facing particularly demanding and complex tasks.

In accordance with the vision of science education expressed in the latest NGSS documents (NGSS Lead States, 2013), which call for students’ engagement in sophisticated scientific practices through evidence-based, collaborative inquiry tasks with many possible outcomes, science students in many SSRL studies (e.g., Grau & Whitebread, 2012; Iiskala et al., 2015; Ucan, 2017; Ucan & Webb, 2015) were engaged in ill-structured group tasks. Such ill-structured, real group tasks cannot be completed by individual students working alone and therefore require group members to engage in egalitarian exchange and evaluation of ideas, hypothesis, and strategies (E. G. Cohen, 1994a; Shin, Jonassen, & McGee, 2003). Ill-structured tasks often have ambiguously defined goals and all elements of the problem may not be immediately apparent to the learners at the onset of the collaborative activity (Shin et al., 2003). Moreover, Shin and colleagues (2003) pointed out that ill-structured tasks have more than one
solution or solution path, thus choosing a course of action and predicting the outcomes of various cases is difficult. Shin et al. stressed that learners working on ill-structured tasks need to make and defend their judgements about the problem interpretation and need to be able to apply multiple criteria to evaluate solutions. Thus far, SSRL researchers have not investigated whether SSRL processing in science differs from SSRL processing in other domains. Although Ucan (2017) studied students’ SSRL while they worked on ill-structured science tasks of increasing complexity, SSRL research in science education would benefit from even greater attention to the very complex and nuanced aspects of science that are growing foci in NGSS and standards reform.

Science-specific and in-depth SSRL studies would help illuminate both the domain-specific challenges faced by collaborative groups in science that might be impeding groups’ work as well as how groups grapple with those challenges. Although there is no single best mode or way of regulation of learning, it is important to understand how groups adaptively regulate to internal and external factors to overcome encountered problems. Hence, the research purpose of my study is to contribute to the knowledge on group regulation of learning when faced with the domain specific challenge of uncertainty that enters through collaborative inquiry in science, with a long-term goal of understanding how to help learners more thoughtfully and intentionally manage challenges that arise in collaborative inquiry tasks.

**Uncertainty in Science**

One such domain-specific challenge that learners experience during collaborative inquiry in science is the uncertainty that is inherent to thinking, doing, and talking science (Allchin, 2012; Buck, Lee, & Flores, 2014; Lemke, 1990; Osborne, Simon, Christodoulou, Howell-Richardson, & Richardson, 2013). The term *scientific uncertainty* is used to refer to the integral
features of the scientific enterprise manifest as tentativeness of disciplinary knowledge, continuous evolution and social construction of theory-laden, scientific practices, and incompletely discernable scientific phenomena (e.g., Buck et al., 2014; Kirch, 2012; Pollack, 2003). The naïve view of science is that scientific knowledge is fixed and certain, and that scientists should be able to answer all questions about the natural world (Pollack, 2003; Sandoval, Greene, & Bråten, 2016). Contrary to such views, scientific knowledge is tentative and continuously evolving in the light of new evidence and/or the reinterpretation of existing evidence in light of new questions or theory (Abd-El-Khalick, 2012; T. S. Kuhn, 2012).

Moreover, there are questions that science cannot answer (NGSS Lead States, 2013). Hence, there is uncertainty that is inherent to nature of science (Buck et al., 2014; Manz & Suárez, 2018; Pollack, 2003). Pollack (2003) emphasized that uncertainty of scientific knowledge is sometimes used with negative connotations to imply that scientific knowledge is “unsound” (p. 16) and to dismiss scientists’ expertise. On the contrary, uncertainty in science serves to propel science forward. Scientific uncertainty is multifaceted and it envelops scientific explorations. Pollack further elucidated that in scientific inquiries “[t]he uncertainty arises in many ways, and the nature of uncertainty may change through time, but the scientific endeavor is never free of uncertainty” (Pollack, 2003, p. 5). The uncertainty also stimulates scientific explorations because scientists use it to guide their formulation of new questions to explore as well as the design of new experiments with the goal of refining current models of various systems. For the purpose of this study, I draw on two additional perspectives on uncertainty that are present in the literature: uncertainty as an intrapersonal affective state (e.g., Kagan, 1972; Kirch, 2012) and uncertainty as a characteristic of the situation (Christensen & Fensham, 2012; Sorrentino & Roney, 2000; Tversky & Kahneman, 1974). Understanding the role of uncertainty in collaborative science
inquiry requires considering both perspectives because there is a dynamic interaction between the aspects of the situation and learners’ responses to it. I present a comprehensive discussion of conceptualizations of uncertainty and related terms (e.g., need for closure) in Chapter II. Here, I briefly explain the two perspectives.

Kagan (1972) defined uncertainty as an alerted affective state characterized by “incompatibility between cognitive structures, between cognitive structure and experience, or between cognitive structures and behavior” (Kagan, 1972, p. 54). Thus, Kagan (1972) defined uncertainty as equivalent with the term cognitive dissonance. A person experiencing such dissonance strives to resolve the uncertainty. Kagan (1972) suggested that the motive to resolve uncertainty is one of four different classes of motives that drive human behavior, in addition to the sensory motives (e.g., cessation of pain, warmth, sweet tastes, etc.), the motive to resolve anger and hostility, and the motive for mastery. Indeed, being uncertain is a prerequisite for thinking and exploration (Dewey, 1909). Thus, learners engaged in collaborative science inquiry, who are feeling such personal uncertainty, would either be motivated to work to resolve it or be paralyzed by it.

Uncertainty as a characteristic of a situation, which is the topic of discussions in multiple fields from medicine to behavioral decision making and psychology, is rarely explicitly defined (e.g., Hillen, Gutheil, Strout, Smets, & Han, 2017; Sorrentino & Roney, 2000; Tversky & Kahneman, 1974). In this paper, I define situational uncertainty as the kind of uncertainty that arises in complex situations that are not fully definable, interpretable, or predictable, while also having a multiplicity of possible outcomes and related consequences. For example, a student choosing a graduate school to attend and a patient deciding whether or not to have an elective surgery both face situational uncertainty. In a learning environment, uncertainty as a
characteristic of the situation may arise from ill-structured problems. In collaborative science inquiry, for example, uncertainty may emerge in the planning stages of the inquiry due to the multitude of possible pathways or as uncertainty about the most appropriate investigative methods to employ (Kirch, 2012; Metz, 2004).

In science, the need to find answers to the open questions and resolve, to an extent, the existing uncertainty is a powerful driver for the growth of scientific knowledge (Feynman, 1998; T. S. Kuhn, 2012; Pollack, 2003). At a macro level, scientific uncertainty refers to the nature of science and tentativeness of scientific knowledge (Feynman, 1998; T. S. Kuhn, 2012). As such, uncertainty is one of the major driving forces for production of scientific explanations about the way the world works (Dewey, 1909; Kirch, 2012). Science progresses through periods of what T. S. Kuhn (2012) called “normal science” (p. 10), during which scientists cumulatively add support and refinement to the existing paradigm. In addition, there are scientific revolutions, which are “non-cumulative developmental episodes in which an old paradigm is replaced in whole or in part by an incompatible new one” (T. S. Kuhn, 2012, p. 92). Novel theories that emerge through the scientific revolution are able to account for unresolved anomalies discovered during the preceding period of normal science under the old paradigm (T. S. Kuhn, 2012). Hence, scientific knowledge advances through periods of agreements and disagreements and through processes that both raise and resolve uncertainties.

Kruglanski, Pierro, Mannetti, and De Grada (2006) argued that such macro-level phenomena are grounded in micro-level processes that are observable in the interactions of learners in small collaborative groups. At the micro level, which is the one of interest in my study, groups of learners engaged in collaborative inquiry in science encounter scientific uncertainty that includes uncertainty related to investigative procedures, observations,
interpretations, generalizability, and application of the findings, and the fit of findings with the existing knowledge (Kirch & Siry, 2012; Metz, 2004). The ability to identify, understand, articulate, and address scientific uncertainty is a critical part of a robust scientific literacy that can withstand demands of decision making in a global society characterized by uncertainty (Buck et al., 2014; Christensen & Fensham, 2012).

However, people differ in how they cope with the encountered uncertainty (Sorrentino, Holmes, Hanna, & Sharp, 1995; Sorrentino & Roney, 2000). These ways of coping with uncertainty are referred to as a person’s uncertainty orientation, with uncertainty-oriented (UO) individuals being on one end of the continuum and certainty-oriented (CO) individuals being on the other end (Sorrentino & Roney, 2000). UO individuals orient toward uncertainty, i.e. they tend to approach it, engage in exploration, and think deeply and effortfully in order to resolve it (Sorrentino & Roney, 2000). In contrast, CO persons perceive uncertainty as something to be avoided, orienting themselves toward maintaining certainty and clarity of their present worldview, and seeking out situations that do not raise ambiguity or confusion (Sorrentino & Roney, 2000). People with different uncertainty orientations respond differently to uncertain and ambiguous situations and are likely to do so when the uncertain situations are also infused by inherent disciplinary uncertainty (i.e., scientific uncertainty). Thus, it is reasonable to expect that learners in collaborative groups engaged in science inquiry will experience and deal with scientific uncertainty in different ways. In turn, such differences may contribute to creating challenges that necessitate groups’ engagement in social regulation of learning. For example, a small group of students engaged in collaborative inquiry regarding an ill-structured topic such as climate change may encounter several challenges regarding uncertainty (e.g., personal unfamiliarity with the topic, accuracy and validity of measurements of the Earth’s surface
temperatures, incompleteness of the conceptual model of the phenomenon, etc.), and thus need to enact SSRL to successfully navigate the challenges these various kinds of uncertainty present.

The purpose of my study is to explore how groups of science learners engaged in collaborative inquiry respond to the uncertainties encountered during inquiry and how they engage in collective regulation of their learning to overcome challenges and complete learning tasks.

**Preservice Teachers, Collaborative Inquiry, and Uncertainty**

Whereas the locus of collaborative science learning is the group, teachers play a critical role as facilitators and orchestrators of collaborative inquiry (Borge & White, 2016; Hmelo-Silver & Barrows, 2008; Warwick, Mercer, Kershner, & Staarman, 2010; Webb, 2009). Findings from a meta-analysis (e.g., Furtak, Seidel, Iverson, & Briggs, 2012) suggested that guided inquiry in science, in which the teacher strategically guides and supports students’ efforts while allowing space for students to enact coRL and SSRL (e.g., Veermans, Lallimo, & Hakkarainen, 2005) is more effective than student-led inquiry. Students in science classrooms where teachers were confident and proficient facilitators of group learning engaged in higher level cognitive activities (Blumenfeld & Meece, 1988; McNeill et al., 2013; Tal, Krajcik, & Blumenfeld, 2006) and showed higher learning gains (McNeill et al., 2013; Mercer, Dawes, Wegerif, & Sams, 2004) than students who participated in teacher-centered instruction. Conversely, researchers have also documented the negative influence of teachers on collaborative outcomes related to the deficient design of collaborative tasks (Arvaja, Häkkinen, Eteläpelto, & Rasku-Puttonen, 2000; Krajcik et al., 1998) and insufficient support of collaborative groups (Blumenfeld & Meece, 1988; Veermans & Järvelä, 2004).

Thus, it is of critical importance that teachers as designers and orchestrators of science inquiry are well-prepared to support students participating in collaborative inquiry. Moreover,
the emphasis on scientific practices in the NGSS (NGSS Lead States, 2013) means that science teachers need to be able to engage their students in authentic explorations that approximate the practice of real scientists and are thoughtfully adapted for the students’ development level (Abd-El-Khalick, 2012). Authentic explorations preserve native characteristics of scientific inquiry, such as uncertainty, and serve as a take-off point for making those characteristics explicit to the community of learners (Abd-El-Khalick, 2012; Manz & Suárez, 2018). When students encounter scientific uncertainty, they have to make decisions about their inquiry (i.e., how to frame the investigation, to how to conduct it, how to interpret the data, etc.). In that way, scientific uncertainty could be used as a resource in the science classroom and serve to establish the need for scientific practices (Manz & Suárez, 2018), shaping discourse in the learning environment.

Researchers have found that preservice science teachers’ perceptions of and beliefs about inquiry-based teaching, which influence their emerging pedagogical practice (Bencze, Bowen, & Alsop, 2006), can be supported or thwarted as the result of their participation in science methods courses (N.-H. Kang, 2008; Pilitsis & Duncan, 2012; Windschitl & Thompson, 2006) and field teaching experiences (Fazio, Melville, & Bartley, 2010; N.-H. Kang, 2008; Soprano & Yang, 2013). Enabling preservice teachers to develop coherent and robust understanding of collaborative inquiry in science, consistent with three-dimensional NGSS, means providing holistic opportunities and support to preservice teachers in science methods courses (N.-H. Kang, 2008; Pilitsis & Duncan, 2012). Such opportunities should include participation in collaborative inquiry learning, planning of collaborative inquiry lesson units, field placement with teachers who model collaborative inquiry-based teaching, and critical reflection on preservice teachers’ teaching and learning experiences (Fazio et al., 2010). It should also incorporate and emphasize
explicit discussions and explorations of characteristics inherent to the science inquiry and scientific enterprise (Abd-El-Khalick, 2012; Abd-El-Khalick & Lederman, 2000).

Researchers have investigated students’ capacity for grappling with scientific uncertainty during collaborative inquiry (Kirch & Siry, 2012; Metz, 2004) but pre- and in-service teachers’ knowledge and understanding of scientific uncertainty as a defining characteristic of science remains under-researched. Previous research involving pre- and in-service teachers and scientific uncertainty can be categorized into two broad strands: (a) research focused on scientific uncertainty as one of the important elements of a constructivist learning environment (e.g., Haney & McArthur, 2002; Johnson & McClure, 2004); and (b) research focused on a particular aspect of scientific uncertainty, such as uncertainty of scientific evidence (e.g., Ruhrig & Höttecke, 2015) or measurements (e.g., Priemer & Hellwig, 2018). Researchers have relied on the use of a five-scale instrument, the Constructivist Learning Environment Survey (CLES), to gain an insight into students’ and teachers’ perceptions of their learning environment (Johnson & McClure, 2004; Taylor & Fraser, 1991; Taylor, Fraser, & Fisher, 1997). The five scales include scientific uncertainty, personal relevance, critical voice, shared control, and student negotiation as key descriptors of a constructivist learning environments (Taylor et al., 1997). However, as Taylor and colleagues (1997) pointed out, observations of classroom practices often differ from practices that students’ and teachers’ self-reported through their CLES survey responses (e.g., Thao-Do, Bac-Ly, & Yuenyong, 2016). Thus, this strand of research provided little direct insight into pre- and in-service teachers’ knowledge of scientific uncertainty and their capacity to navigate through it. The main critique of studies that focus on just one aspect of scientific uncertainty is they espouse fragmented approaches to researching teachers’ ability to address
scientific uncertainty and do not contribute to the teachers’ building of comprehensive understanding of scientific uncertainty as inherent to the scientific enterprise as a whole.

One exception is a recent study by Manz and Suárez (2018), who worked with seven second-grade teachers to help them reframe their students’ science learning toward meaningful participation in scientific practices, consistent with NGSS. Manz and Suárez found that the teachers’ development of a more sophisticated view of scientific uncertainty was of critical importance for teachers’ ability to transform curriculum toward reform-based instruction and engage their students in more authentic scientific practices. Manz and Suárez focused on the tensions teachers faced when they tried to incorporate scientific uncertainty into the curriculum and development of effective teaching strategies. However, the authors did not focus on teachers’ own comfort with scientific uncertainty or processes that facilitate its negotiation.

If science teachers are to implement and support effective collaborative inquiry that, in accordance with the latest standards documents (NGSS, 2013), helps students build knowledge of science content and practices, as well as collaborative skills, it is important that they are also able to foster and expand students’ capacity for social regulation of learning, which is required for successful collaboration and navigation of scientific uncertainty (Hadwin et al., 2018; Järvelä & Hadwin, 2013; Järvelä et al., 2013; Manz & Suárez, 2018; Metz, 2004). To date, there are no studies investigating social regulation of learning in small-groups of science learners dealing with scientific uncertainty. Hence, additional research is needed to illuminate regulative processes relevant for addressing uncertainty as the defining aspect of scientific enterprise and an integral part of scientific practices. Preservice elementary school teachers are an especially interesting population of science learners to study because of the dual nature of their role as science students and as future teachers, poised to influence learning outcomes of their students.
In this dual role, preservice elementary school teachers are concurrently learning what it is like to be a learner in collaborative inquiry and how to structure and manage collaborative inquiry for the teaching and learning of science. In this study, I will focus on preservice elementary school teachers as science learners. However, I am aware that these learning and teaching experiences during their teacher preparation courses serve to shape novice teachers’ future actions (Liston & Zeichner, 2014) as they begin to either affirm or challenge their apprenticeship of observation (Boyd, Gorham, Justice, & Anderson, 2013; Killeavy & Moloney, 2010; Schön, 1987) and situate themselves among and within educational traditions (Liston & Zeichner, 1990). A closer look at how preservice teachers respond to inquiry tasks that vary in their level of structure would be helpful for building an understanding of preservice teachers’ existing acumen of skills related to dealing with and regulating through scientific uncertainty as well as for identifying specific challenges and inflection points in collaborative inquiry in science that trigger social regulation of learning related to uncertainty.

**Purpose of the Study**

The purpose of the present study was to explore how social regulation of learning, uncertainty, and tasks interact in the context of scientific inquiry. I was interested in investigating how scientific uncertainty and differing degrees of situational uncertainty that collaborative groups of preservice elementary school teachers encounter during scientific inquiry might prompt and shape their social regulation of learning. To investigate different levels of uncertainty, I observed how preservice teachers organized in small four-person groups collaborated on scientific inquiry tasks that varied in their level of structure; in other words, how well-structured versus ill-structured they were (Shin et al., 2003). First, to determine preservice teachers’ typical ways of dealing with uncertainty, I administered measures of uncertainty
orientation. Then, I assigned preservice teachers to collaborative groups based on their uncertainty orientations with an aim of ensuring variability within and among groups. Next, collaborative groups engaged in a non-inquiry collaborative task to establish a base-line of group dynamics. Then, I observed groups’ regulation of learning at five different time points in semester.

I gathered video-recordings of the groups’ collaborative work as my primary data source. In addition, for my secondary data sources, I collected field observation notes during the collaborative sessions. Also, I used preservice teachers’ responses to the pre-task questions and their reflective blogs written over the course of the semester to gain an insight into their thinking about their collaborative inquiry experiences and the encountered uncertainty.

In this multimethod study, I used discourse analysis as a primary method of interpreting and understanding groups’ regulation of learning. As is customary in qualitative research tradition, I framed my research questions to be broad enough to allow for flexibility and in-depth, grounded description of the phenomenon under study (i.e., social regulation of learning in science inquiry; Corbin & Strauss, 2015). Developing bottom-up descriptions and understanding of the role of uncertainty in preservice elementary school teachers’ social regulation of learning during collaborative inquiry required staying open-minded and being aware of my own positionality (Corbin & Strauss, 2015; C. Marshall & Rossman, 2016). Qualitative analysis of the data was complemented by the quantitative analysis of uncertainty orientation measures (Sorrentino et al., 1995; Sorrentino & Roney, 2000) and the coded regulative processing data. I used measures of preservice teachers’ uncertainty orientations to assign participants to groups and to describe and understand their individual ways of dealing with uncertainty, as well as how their personal uncertainty orientation might relate to group regulation of learning. Quantitative
analysis of the coded regulative processing data provided a more complete picture of groups’ social regulation of learning.

**Research Questions**

To explore preservice elementary school teachers’ social regulation of learning when they encounter situational uncertainty during scientific inquiry, I operationalized different degrees of situational uncertainty as varying levels of task structure (i.e., ranging from well- to ill-structured). I proposed the following research questions:

- **Research Question 1:** How do collaborative groups of preservice elementary school teachers regulate their learning when they encounter scientific uncertainty inherent in the task?
- **Research Question 2:** How does preservice elementary school teachers’ enactment of social regulation of learning vary with respect to differences in the degree of situational uncertainty encountered during collaborative inquiry tasks?
- **Research Question 3:** How does regulation of learning during collaborative inquiry differ for people of different uncertainty orientations?

**Significance of the Study**

My study contributes to the understanding of social regulation of learning that becomes necessary when learners encounter uncertainty during collaborative inquiry in science as they participate in tasks that fall at different points along the well-structured versus ill-structured task continuum (Shin et al., 2003). I focused on preservice elementary school teachers as learners and aimed to explore and describe how they jointly address and overcome challenges in scientific inquiry. To this aim, I invoked research in psychology, science education, and SSRL. Developing an understanding of how preservice elementary school teachers collectively regulate
their learning in the face of scientific uncertainty that is an integral part of scientific practices is important because it advances knowledge about preservice teachers as collaborative learners in science and as well as novice teachers who will shortly after their graduation be responsible for implementing effective and authentic collaborative science inquiry in their own classroom and helping prepare their young students for the uncertain and complex world.

This exploratory, multimethod, in-situ study contributes to knowledge about preservice elementary school teachers’ social regulation of learning during collaborative inquiry in science and aims to inform hypothesis generation for future studies focused on domain-specific aspects of social regulation of learning in science. My study also contributes to the methodological variety in the field of research on social regulation of learning that is necessary to start building a contextualized understanding of social regulation of learning in science and identifying domain-specific challenges and regulative triggers that small-groups experience. Additionally, my study helps science teachers, as well as science teacher educators, who are interested in designing effective collaborative inquiry engagements that build students’ social and regulative skills as well as scientific knowledge robust enough for the uncertain world that awaits them.

**Researcher Positionality**

Prior to undertaking this study, I have served as a research assistant with one cohort, and as a teaching assistant with another cohort of preservice teachers, in the same elementary science method class in which this study will take place. Thus, I have good knowledge and understanding of the environmental context, curriculum, and demands placed on the preservice elementary school teachers in this class. Through my undergraduate training in physics as well as my previous career as a medical physicist and a project manager in high-tech industry, I also have rich personal experiences with uncertainty in complex scientific inquiry and engineering.
projects. I understood that all of these experiences provided me with valuable insight about study participants and phenomenon under study, but also had the potential to contribute to biased interpretation of the findings. I believe that it is possible to improve people’s ability to collaboratively solve scientific problems that inherently involve uncertainty and that social-regulation of learning plays a significant role in that endeavor. To address my subjectivity and protect credibility and trustworthiness of the study, in addition to data triangulation, I have engaged in self-reflection throughout all phases of the study, as well as regular peer debriefings with academic advisors and mentors (Corbin & Strauss, 2015; C. Marshall & Rossman, 2016).
CHAPTER 2: LITERATURE REVIEW

In this chapter, first I provide a review of the literature on aspects of preservice elementary school teachers’ knowledge relevant for participation in and implementation of collaborative inquiry in science. In authentic science inquiry, uncertainty is integral and, hence, an unavoidable part of the learning. In this study, my goal is to describe how uncertainty can trigger the need for social regulation of learning in collaborative groups. To this aim, I review relevant conceptualizations of uncertainty from the science education and psychology literatures. In my review of the science education literature, I focus on conceptualizations of scientific uncertainty in science education, and I review theoretical models of scientific uncertainty. In the section on psychology literature, I review relevant constructs from social psychology and then focus on uncertainty orientations. Given that collaborative inquiry is a cornerstone of science education, of particular interest are empirical studies that illuminate how people’s uncertainty orientations might shape group dynamics and, specifically, group learning. Finally, I review literature on SRL and SSRL, which illuminates how group members work together to regulate their learning and overcome encountered challenges, such as uncertainty.

Preservice Teachers, Scientific Practices, and Pedagogical Content Knowledge

In this study, I will view preservice elementary school teachers as science learners. However, the literature on preservice teachers’ knowledge relevant for participation in and orchestration of collaborative inquiry contributes the background information helpful for understanding why it is important to afford them opportunities to engage in the type of science
and engineering practices they will be expected to implement in their classrooms. It is ultimately teachers’ responsibility to execute the new vision of science education based on the new three-dimensional NGSS, which calls for students’ active engagement in authentic collaborative scientific practices as they apply crosscutting concepts to build and expand their understanding of the key disciplinary ideas in the fields of physical, life, earth and space sciences; and engineering, technology, and applications of science (NGSS Lead States, 2013; NRC, 2015).

Authentic scientific practices in science classrooms require the exploration of problems that faithfully approximate, rather than design out, the relevance, complexity, controversy, and uncertainty that characterize scientific enterprise and that require students’ collaboration, imagination, and creativity to progress toward solutions (Ford, 2015; Kirch, 2012; Manz & Suárez, 2018; Osborne, 2014). However, as Osborne (2014) pointed out, prior to coming to their teacher preparation programs, a majority of preservice teachers themselves have not received science education that would help them develop sound understanding of scientific practices and related procedural (i.e., knowing how to conduct reliable investigations) and epistemic knowledge (i.e., knowing why such scientific practices and procedures are necessary). Thus, to understand affordances and hindrances related to science teachers’ participation in and implementation of authentic collaborative inquiry it is important to consider teachers’ knowledge, beliefs, and individual differences.

Future elementary school teachers, who are generalists rather than science subject matter specialists, face a particularly challenging situation when attempting to develop sound, NGSS aligned pedagogical practices (NRC, 2015; Davis & Petish, 2005). As they are expected to teach multiple subjects, many pre- and in-service elementary school teachers lack science subject matter knowledge (SMK; Peters-Burton & Botov, 2017) and express misconceptions similar to
those held by their students (Burgoon, Heddle, & Duran, 2010; Lambert, Lindgren, & Bleicher, 2012; Trundle, Atwood, & Christopher, 2006; Vaughn & Robbins, 2017). Related to their insufficient SMK, elementary school teachers also express a lack of confidence for teaching science (Bleicher, 2007; van Driel, Berry, & Meirink, 2014). Teachers with insufficient SMK tend to choose ineffective instructional approaches, such as inadequate instructional representations and activities that forgo science content to emphasize fun and, in the end, lead to little science learning (Davis & Petish, 2005; Peters-Burton & Hiller, 2013). Conversely, well-developed and coherent SMK, although not sufficient, is a necessary pre-requisite for development of teachers’ pedagogical content knowledge (PCK; van Driel et al., 2014).

Shulman (1987) conceptualized PCK as a unique category of teacher knowledge, which is “the special amalgam of content and pedagogy” (p. 8). As such, well-developed PCK is of critical importance for teachers’ ability to orchestrate effective science instruction. The focus on scientific practices and realization of the NGSS vision of science education necessitates that teachers develop “new knowledge of the ideas and practices in the disciplines of science, an understanding of instructional strategies that are consistent with the NGSS vision, and the skill to implement those strategies in their classrooms” (NRC, 2015, p. 2). Hence, if there is a need to help teachers build PCK knowledge associated with science as practice-based activity, such knowledge should be founded in activity (Osborne, 2014). Consistent with the science teachers’ knowledge called for by the NRC (2015), in the most recent model of PCK, Gess-Newsome (2015) defined PCK as “both a knowledge base used in planning for and the delivery of topic-specific instruction in a very specific classroom context, and as a skill when involved in the act of teaching” (pp. 31-32).
Over time, researchers have posited different models of PCK for science teaching (e.g., Gess-Newsome, 2015; Grossman, 1990; Loughran, Mulhall, & Berry, 2004; Magnusson, Krajcik, & Borko, 1999; Park & Oliver, 2008). Some models (e.g., Grossman, 1990; Magnusson et al., 1999) draw on Shulman (1986, 1987) who distinguished between seven categories of teachers’ knowledge: (a) subject matter content knowledge; (b) PCK; (c) curricular knowledge; (d) general pedagogical knowledge; (e) knowledge of students; (f) knowledge of educational contexts; and (g) knowledge of educational aims and values, as well as their philosophical and historical bases. Models stemming from Shulman’s original conceptualization of PCK, in which PCK is separate from SMK, can be thought of as transformative models (Kind, 2009). Other models, called integrative models, differ from Shulman’s original model by the inclusion of SMK in PCK (Kind, 2009). The main critique of integrative models is that they lack explanatory power to explain the mechanisms through which PCK develops (Abd-El-Khalick, 2006; Kind, 2009). Transformative models are more effective for explaining development of teachers’ PCK and factors that affect it.

The majority of the researchers who have studied development of science teachers’ PCK have relied on a transformative model by Magnusson et al. (1999; e.g., R. Cohen & Yarden, 2009; Demirdögen, 2016; Park & Chen, 2012), but other representations have been used as well (Davidowitz & Rollnick, 2011; Nilsson & Loughran, 2012). Magnusson et al. conceptualized PCK for science teaching as consisting of five distinct components: (a) orientations toward science teaching, (b) knowledge of science curricula, (c) knowledge of students’ understanding of science, (d) knowledge of instructional strategies, and (e) knowledge of assessment of scientific literacy. Magnusson and colleagues defined orientations toward teaching science as “teachers’ knowledge and beliefs about the purposes and goals for teaching science at a
particular grade level” (p. 97), positioning it as an overarching component that shapes and is shaped by the other four PCK components. Friedrichsen, Driel, and Abell (2011) re-conceptualized science teaching orientations as a multidimensional set of interconnected beliefs about the goals and purposes of science education, views of the nature of science, and beliefs about science teaching and learning, including beliefs about roles of teachers and students.

Studies of the development of PCK focus on integration of the PCK components and interactions among them (e.g., Brown, Friedrichsen, & Abell, 2013; Demirdögen, 2016; Hanuscin, 2013; Kaya, 2009; Park & Chen, 2012; Park & Oliver, 2008). Teachers’ development of PCK has some common characteristics (e.g., gaining a better understanding of students’ misconceptions led to improvements in PCK), but there are also characteristics unique to each teacher’s PCK, driven by their science teaching orientations, personal differences, teaching experiences, and characteristics of the students they teach (R. Cohen & Yarden, 2009; Park & Oliver, 2008). Science teachers’ orientations toward teaching science provide a lens through which a teacher shapes their individual PCK (Demirdögen, 2016), and serve to support (Hanuscin, 2013) or limit development of teachers’ PCK (Brown et al., 2013; N.-H. Kang, 2008). Science teachers’ orientations toward teaching science stem from teachers’ own schooling experiences (Brown et al., 2013). Orientations and beliefs formed through such apprenticeship of observation (Lortie, 1975) are resistant to change (Brown et al., 2013). Apprenticeship of observation refers to the time students spend in schools observing their teachers’ pedagogical practices and forming perceptions and beliefs about teaching based on their observations (Boyd et al., 2013). Specifically, teachers’ orientation toward science teaching as teacher-centered, lecture-based practice hindered development of their PCK for inquiry-based science teaching (Brown et al., 2013; Park & Chen, 2012; Usak, Ozden, & Eilks, 2011).
In addition to teachers’ orientations toward teaching science, researchers found that SMK can foster or limit development of teachers’ PCK (De Jong, van Driel, & Verloop, 2005; Kaya, 2009; Nilsson, 2008; Usak et al., 2011). In cases where teachers’ SMK was not high, PCK was very limited (Davis & Petish, 2005; Kaya, 2009). As teachers’ SMK improved, so did their knowledge of students’ misconceptions and the appropriate instructional strategies to diagnose and address them (De Jong et al., 2005; Nilsson, 2008; Park & Oliver, 2008). Researchers have emphasized the important role of reflection in enabling teachers to evolve their PCK, through gaining insights not only into their teaching practice and reasons for it, but also into their own schooling experiences (Brown et al., 2013; De Jong et al., 2005; Demirdöğen, 2016; Nilsson, 2008). Teachers’ PCK develops through teaching experience (De Jong et al., 2005; Nilsson, 2008; Park & Oliver, 2008), but also through learning about teaching science (Nilsson & Loughran, 2012). Thus, supporting novice teachers in the development of pedagogical practices that match the NGSS vision and requirements means affording them opportunities to experience science instruction of the same kind they are expected to implement. Effectively supporting preservice teachers in participation in authentic inquiry necessitates an understanding of critical moments that occur when preservice teachers encounter uncertainty during collaborative inquiry.

**Conceptualizations of Uncertainty**

Uncertainty is inherently present in authentic scientific practices and inquiry (Buck et al., 2014; Manz & Suárez, 2018; Metz, 2004; Pollack, 2003). Therefore, managing uncertainty in science inquiry is a key part of science learners’ acumen. To build an understanding of how groups of learners engaged in scientific inquiry navigate through the encountered uncertainty, it is helpful to draw on conceptualizations of uncertainty present in science education literature as well as those from psychology literature. Perspectives on uncertainty from the science education
literature illuminate ways in which researchers from different strands of scholarship have approached uncertainty in science as global characteristics of scientific enterprise (i.e., nature of science research strand), and as an inherent part of scientific practices and inquiry (i.e., scientific uncertainty strand). I refer to the former as the macro-level perspective on uncertainty in science education and to the latter as the micro-level perspective on uncertainty. Constructs related to uncertainty from psychology literature provide insight into individual differences in dealing with uncertainty and how these individual differences, in turn, might shape individual behaviors and group interactions.

**Conceptualizations of uncertainty in science education.** In science education, researchers who have studied nature of science (NOS), that is values, beliefs, and assumptions that are integral to the generation and validation of scientific knowledge (Lederman, 1992) have studied uncertainty from the macro-level. Conversely, researchers who have studied scientific uncertainty as an inherent part of scientific inquiry have approached it from the micro-level. Both approaches matter because they help elucidate some of the constraints and challenges that learners experience when they encounter scientific uncertainty, as well as possibilities for fostering adaptive ways of dealing with uncertainty during collaborative inquiry. Researchers have shown that the understanding, or lack thereof, of scientific uncertainty plays an important role in people’s decision making related to complex socio-scientific and health issues as well as the use of new technologies (e.g., Christensen, 2007; Doble, 1995; Kolstø, 2006; Retzbach & Maier, 2015). Science learners’ capacity to effectively deal with uncertainty is becoming increasingly important. For example, in a recent study with more than 2,500 adult participants, Pepper et al. (2019) investigated how individuals respond to information about electronic vaping products (EVPs). Participants were randomly provided with either a control message, which
included a factual statement about EVPs, or a scientific uncertainty message that, in addition to the control message, included information about limits and lack of clear conclusions of the current research on EVPs. The authors found that people who viewed the message about scientific uncertainty rated vaping as less risky than people who viewed the control message (Pepper et al., 2019). This example is illustrative of the serious consequences that lack of understanding of scientific uncertainty might have for individuals as well as of the pressing need to help people develop scientific literacy that includes the ability to identify, articulate, evaluate, and grapple with scientific uncertainty (Kirch, 2012).

**Nature of science.** Development of scientific literacy (i.e., knowledge of science that includes the ability to critically evaluate and apply that knowledge for informed decision-making of personal and societal importance) is one of the longstanding goals of science education (Roberts & Bybee, 2014; Sadler, Chambers, & Zeidler, 2004). Robust understanding of the nature of science (NOS) is an important component of scientific literacy (NGSS Lead States, 2013; Abd-El-Khalick & Lederman, 2000; Khishfe, 2012; Schwartz & Lederman, 2002). Moreover, Lederman, Antink, and Bartos (2014) stressed that “[i]t is not the K-12 teacher’s goal to create philosophers of science. The goal is to develop informed citizens so decisions can be made concerning personal and societal issues that are scientifically-based” (p. 291). Staying mindful of the prospective elementary teachers who will be participants in my study, it is important to understand the factors that might help or thwart preservice teachers’ achievement of this goal. Although there is no agreement on a singular definition of NOS within science education, in this paper, I use the term NOS to refer to the aspects of scientific knowledge that emanate from the ways in which participants in the science community create scientific knowledge (i.e., scientific practices and inquiry; Lederman et al., 2014; Lederman & Lederman,
Thus, more esoteric discussions that characterize this field of research regarding the
definition of NOS and comprehensive listing of aspects of NOS (see Lederman & Lederman,
2012, 2014), are beyond the scope of this paper. Instead, I focus on those aspects of NOS that are
uncontested in the field and that provide a sound base for engaging students in meaningful and
authentic scientific practices.

Lederman et al. (2014) posited that, at the level of K-12 education, those uncontested
characteristics of NOS include that scientific knowledge is socially and culturally created, relies
on human inference, imagination, and creativity, and thus, is subjective. Scientific knowledge is
empirically-based and is, therefore, tentative, and subject to change as the new evidence emerges
(Lederman et al., 2014). Two additional generally agreed upon aspects of NOS are the
distinction between observations and inferences and relationships between and functions of
scientific theories and laws (Abd-El-Khalick, 2001). At the beginning of their teacher education
courses, many preservice science teachers hold naïve views of NOS, such as scientific laws are
unchangeable because they have been proven true or there is one right scientific method that
follows a well-established sequence of steps (Abd-El-Khalick, 2001; Abd-El-Khalick &
Akerson, 2004; Mesci & Schwartz, 2017). If science teachers themselves hold naïve views of
NOS, it is not likely that they will be able to help their students develop sophisticated
conceptions of NOS in line with the latest reform documents (Akerson & Volrich, 2006). Hence,
science teacher educators have explored ways in which they could help teachers develop
advanced views of NOS.

Teacher educators have relied on both implicit (Barufaldi, Bethel, & Lamb, 1977;
Scharmann & Harris, 1992) and explicit (Abd-El-Khalick & Akerson, 2004; Akerson &
Hanuscin, 2007) approaches to improve teachers’ conceptions of NOS (Abd-El-Khalick &
Implicit approaches, based on the assumption that teachers can learn about NOS by simply engaging in scientific inquiry, have proven to be less effective than explicit reflective approaches, which include explicit discussions of and reflections on NOS (Abd-El-Khalick & Lederman, 2000). Whereas explicit reflective instruction in science methods courses helped teachers transform their views of NOS, not all participants revised their views to the same degree or in the desired direction of increasing sophistication (Abd-El-Khalick & Akerson, 2004; Mesci & Schwartz, 2017). Moreover, some researchers found certain aspects of NOS (i.e., tentative nature of science, distinguishing between scientific theories and laws, and sociocultural influences on creation of scientific knowledge) more resistant to change (Mesci & Schwartz, 2017; Milner, Sondergeld, & Rop, 2014).

In terms of the factors affecting changes in teachers’ understanding of NOS, researchers found that cognitive (Abd-El-Khalick & Akerson, 2004), as well as instructional, motivational (i.e., personal and social motivation), and sociocultural factors (Abd-El-Khalick & Akerson, 2004; Mesci & Schwartz, 2017) influence how teachers’ NOS views will change as well as which aspects of NOS will evolve. Teachers who engaged in deep content processing (e.g., making connections between classroom discussions, readings, and assignments) and metacognitive monitoring strategies showed greater improvements in their understanding of NOS than the teachers who did not make efforts to make connections across different contexts and who did not engage in metacognitive monitoring of their NOS views (Abd-El-Khalick & Akerson, 2004). As might be expected, instructional choices of activities, examples, and assigned readings played a role in facilitating changes in teachers’ views of aspects of NOS (Mesci & Schwartz, 2017). Teachers who were able to internalize the importance of the understanding of NOS for science learning showed higher personal and social motivation for
changing their existing NOS views (Abd-El-Khalick & Akerson, 2004; Mesci & Schwartz, 2017). For example, Abd-El-Khalick and Akerson (2004) found that preservice teachers who experienced significant change in their NOS views toward the more informed view showed a commitment to changing their misconceptions early on in the course and were motivated by the desire to be competent science teachers.

Last, sociocultural factors (termed worldview factors by Abd-El-Khalick and Akerson, 2004), might act as a barrier to changes in teachers’ views of NOS if they perceive religion and science to be in opposition to each other and seek to apply the standard of absolute “truth,” typically aligned with religious perspectives, to the scientific enterprise (Abd-El-Khalick & Akerson, 2004; Mesci & Schwartz, 2017). In a recent study, Mesci and Schwartz (2017) illuminated that personal differences, such as “reluctance to accept ambiguity” (p. 344), in addition to differences in teachers’ educational and sociocultural backgrounds might also be related to if and how their views of NOS change during teacher preparation courses. Similarly, Abd-El-Khalick (2001) pointed out that intolerance of ambiguity might have affected decision-making of students who seemed to have developed advanced views of NOS. When faced with a complex socio-scientific issue and asked to make a decision, such students still desired definitive scientific answers and were not able to internalize the notion that although there was scientific uncertainty it was still possible to evaluate the competing claims about the natural world and judge their validity. Even after they participated in well-designed NOS instruction, those students shifted to a naïve relativist worldview, characterized by the belief that if there is any scientific uncertainty present then all claims are equally valid (Abd-El-Khalick, 2001). Hence, participation in explicit reflective NOS instruction might not be sufficient for supporting students
in their development of robust, overarching frameworks for thinking about science that transfer to different contexts and issues (Abd-El-Khalick, 2003).

To better understand how individual differences contribute to the shaping of learners’ views of scientific enterprise at the macro level, it may be helpful to consider how learners respond to uncertainty at the micro level, when uncertainty emerges during participation in collaborative inquiry in science. Affording science learners opportunities to grapple with uncertainty and understand themselves and their collaborators as active agents in scientific practices and knowledge building is an important step in fostering a holistic understanding of scientific uncertainty. If learners come to an understanding that uncertainty is an integral and unavoidable part of science at the micro-level and learn how to recognize, articulate, and deal with it in and through inquiry, they will gain a foundation for developing an understanding of uncertainty as a characteristic of science at the macro level.

Scientific uncertainty. Whereas the development of sound scientific literacy is one of the longstanding goals of science education (Lederman & Lederman, 2012), calls for explicitly addressing and developing students’ comprehensive understanding of scientific uncertainty have intensified in recent years (e.g., Kirch, 2012; Kolstø, 2006; Manz & Suárez, 2018; Schroeder, McKeough, Graham, & Norris, 2018). Some researchers have holistically studied scientific uncertainty in inquiry, addressing multiple types of uncertainty that emerged, such as methodological, inductive, and interpretive uncertainty (e.g., Buck et al., 2014; Metz, 2004), whereas others have focused on just one narrow aspect of it, for example measurement uncertainty (Priemer & Hellwig, 2018). Moreover, uncertainty is emerging as a threshold concept in science, specifically in environmental science (J. H. F. Meyer, Land, & Baillie, 2010) and physics (Wilson et al., 2010). Threshold concepts are concepts of great pedagogical
importance that act like gateways to new, transformative ways of thinking about specific subject matter or a discipline (J. H. F. Meyer & Land, 2003; Wilson et al., 2010). Although threshold concepts are initially difficult to grasp, once a learner has comprehended a threshold concept the change is likely irreversible (J. H. F. Meyer & Land, 2003). Threshold concepts are integrative, in other words, they help learners discover previously obscured connections between other concepts within a discipline. Threshold concepts are also bounded to a specific disciplinary area and also potentially troublesome for learners in various ways (J. H. F. Meyer & Land, 2003). For example, if students are not successful in grasping the threshold concept their disciplinary learning path might become blocked (Wilson et al., 2010) and if they are successful, they will have to recognize the more complex nature of their field than they were able to comprehend previously (J. H. F. Meyer & Land, 2003). In science education, once students grasp the threshold concept of scientific uncertainty, they stand to gain the ability to connect their understanding of scientific uncertainty experienced at the micro level through scientific inquiry to the scientific uncertainty at a macro level, as a fundamental part of the scientific enterprise and a driver of scientific progress. Additional examples of threshold concepts from science education are concepts of weight, mass, and gravity, which once internalized by the student underpin the understanding of falling objects, trajectories, and orbits (Bar, Brosh, & Sneider, 2016).

*Measurement uncertainty.* Introducing students to the ways in which scientific knowledge is created, and its nature as both tentative and durable at the same time (Kirch, 2012) necessitates students’ engagement in authentic scientific practices (Chinn & Malhotra, 2002; Driver, Newton, & Osborne, 2000) as well as explicit discussions about and reflections on the nature of science (Abd-El-Khalick, 2012) and uncertainty (Kirch & Siry, 2012). Many science textbook authors have attempted to introduce students to the notion of uncertainty by focusing on
just one aspect of scientific practices, such as measurement, and the uncertainty related to it (Pollock, 2003). Pollock (2003) called uncertainty of measurement the “fundamental level” (p. 63) of uncertainty in science. However, it is important for students to understand the difference between measurement error (i.e., a difference between measured quantity and some reference value) and measurement uncertainty (i.e., variations that happen because of systematic and random influences on the measured quantity), which cannot be controlled (Priemer & Hellwig, 2018).

In this vein, science education researchers (e.g., Abbott, 2003; Alagumalai, 2015; Allie, Buffler, Campbell, & Lubben, 1998; Lubben & Millar, 1996; Priemer & Hellwig, 2018) investigated students’ handling of the measurement uncertainty and errors. Whereas the understanding of measurement errors seems to become more sophisticated in later grades (Lubben & Millar, 1996), levels of understanding found in studies with populations that are expected to be proficient in science suggest that significant room for improvement remains. For example, university students in science education and physics had a tendency to use terms such as uncertainty, error, accuracy, or precision interchangeably and had trouble distinguishing between these concepts or recognizing the need to do so (Alagumalai, 2015; Allie et al., 1998). Even high-school science teachers indicated that there is no need to distinguish between uncertainty and error (Priemer & Hellwig, 2018). Not surprisingly, students’ understanding of measurement did not improve without explicit instruction and areas of students’ improved understanding corresponded to the areas emphasized in instruction (Abbott, 2003). This line of research is important for understanding potential ways to support students’ and teachers’ developing knowledge about multifaceted issues related to the uncertainty of measurement. However, this group of empirical studies is characterized by a compartmentalized approach to
the classroom study of scientific uncertainty. By focusing only on issues of measurement uncertainty this strand of research provides no insight into how understanding measurement uncertainty might relate to students’ ability to identify and adequately deal with other sources of scientific uncertainty that enter during inquiry, for example during the planning of the inquiry or interpretations of the data. Also, it is not clear how understanding measurement uncertainty helps with the development of students’ understanding that uncertainty will always be present.

*Scientific uncertainty in inquiry.* Another group of researchers took a holistic and direct approach to the classroom studies of scientific uncertainty that arises during inquiry. Several researchers studied students’ understanding of scientific uncertainty (e.g., Buck et al., 2014; Kirch, 2010; Kirch & Siry, 2012; Metz, 2004; Schroeder et al., 2018; C. L. Smith & Wenk, 2006) and so far, only Manz and Suárez (2018) focused on teachers’ sense-making about scientific uncertainty. This area of scholarship is characterized by the existence of multiple frameworks and the absence of consistent use of terminology related to the types of uncertainty encountered by the participants in scientific inquiry. Researchers have used multiple terms to indicate the same aspect of scientific uncertainty. For example, Metz (2004) used the term *data as uncertain*, whereas Buck et al. (2014) and Driver et al. (2000) used the term *empirical uncertainty* to denote uncertainty that arises from data that are unreliable, missing, or unobtainable. On the other hand, very similar terms have been used to mark different concepts. For example, Metz used *theory that best accounts for trend as uncertain* to denote uncertainty students expressed about the explanation they have articulated about the observed trend. In contrast, C. L. Smith and Wenk (2006) used *theory-based uncertainty* to refer to the fundamental uncertainty of scientific theories.
The apparent variability is not surprising given that this area of research is expanding and that researchers are still seeking the most effective conceptualizations of scientific uncertainty. I have consolidated terms from the literature related to various types of scientific uncertainty under four categories that are pertinent for my study of the scientific uncertainty students encounter during inquiry: (a) empirical uncertainty; (b) inductive uncertainty; (c) interpretive uncertainty; and (d) conceptual uncertainty (see Table 2). Empirical uncertainty refers to uncertainty about data, data collection procedures and methods. I use inductive uncertainty to refer to uncertainty about trends and patterns in data. Interpretive uncertainty denotes uncertainty about the best theoretical explanation for the observed trends and patterns in data. Conceptual uncertainty refers to the uncertainty originating from incomplete models or insufficient conceptualizations of the phenomenon under study. Whereas researchers have used the first three constructs in empirical studies (Buck et al., 2014; Kirch, 2010; C. L. Smith & Wenk, 2006), I based the construct of conceptual uncertainty on the works of Pollack (2003), who has specified that uncertainty during inquiry can arise due to the incomplete conceptualizations of the phenomena or incomplete models. In my classification, I exclude the work of Allchin (2012), which concerns error rather than uncertainty.

It is important to point out that on a more global, macro-level, all of the identified types of scientific uncertainty refer to “underdetermination of scientific theories by evidence” (Abd-El-Khalick, 2003), which is the notion that evidence alone is never enough to decide between two competing theories. Underdetermination is pervasive in science and can never be eliminated. In addition to scientific reasoning, scientists invoke value judgements to make decisions (Abd-El-Khalick, 2003). However, the proposed classification is useful for exploring the ways in which
science learners deal with different manifestations of underdetermination and attempt to grapple with uncertainty during collaborative inquiry in science.
<table>
<thead>
<tr>
<th>Term used</th>
<th>Author(s)</th>
<th>Description</th>
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<tbody>
<tr>
<td><strong>Methodological uncertainty</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empirical uncertainty</td>
<td>Buck (2014)</td>
<td>Broad uncertainty in the data, without making connections between the data and source of uncertainty</td>
</tr>
<tr>
<td>Empirical uncertainty</td>
<td>Driver, Newton, Osborne (2000)</td>
<td>Uncertainty due to the lack of data</td>
</tr>
<tr>
<td>Pragmatic uncertainty</td>
<td>Driver, Newton, Osborne (2000)</td>
<td>Uncertainty due to the lack of means to investigate a phenomenon of interest (e.g., predicting earthquakes)</td>
</tr>
<tr>
<td>Uncertainty in generating data</td>
<td>Kirch (2010)</td>
<td>Establishing what was done and how it was done during data collection</td>
</tr>
<tr>
<td>Data as uncertain</td>
<td>Metz (2004)</td>
<td>Distrust in the collected data, i.e. acknowledging possibility of error</td>
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<tr>
<td><strong>Inductive uncertainty</strong></td>
<td></td>
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<tr>
<td>Signal uncertainty</td>
<td>Buck (2014)</td>
<td>Uncertainty about trend identified in the data</td>
</tr>
<tr>
<td>Uncertainty in observing</td>
<td>Kirch (2010)</td>
<td>Uncertainty about how the observed trends match observations of others</td>
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<tr>
<td>Trend identified in the data as uncertain</td>
<td>Metz (2004)</td>
<td>Considering the identified trend in data as questionable.</td>
</tr>
<tr>
<td>Generalizability of the trend as uncertain</td>
<td>Metz (2004)</td>
<td>Concern about the extent to which the findings generalize.</td>
</tr>
<tr>
<td>Inductive uncertainty</td>
<td>Smith and Wenk (2006)</td>
<td>Uncertainty related to the hypothesis testing and generalizations as constrained by currently available data.</td>
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<tr>
<td><strong>Interpretive uncertainty</strong></td>
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<tr>
<td>Conceptual uncertainty*</td>
<td>Buck (2014)</td>
<td>Uncertainty about explanation given for an observed trend</td>
</tr>
<tr>
<td>Theoretical uncertainty</td>
<td>Driver, Newton, Osborne (2000)</td>
<td>Uncertainty about interpreting a scientific phenomenon</td>
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<tr>
<td>Uncertainty in interpreting</td>
<td>Kirch (2010)</td>
<td>Uncertainty about what is being interpreted</td>
</tr>
<tr>
<td>Theory that best accounts for the trend as uncertain</td>
<td>Metz (2004)</td>
<td>Doubt about the adequacy of the formulated explanation about the observed trends.</td>
</tr>
<tr>
<td>Interpretive uncertainty</td>
<td>Smith and Wenk (2006)</td>
<td>There are many possible interpretations of the patterns in data.</td>
</tr>
<tr>
<td><strong>Conceptual Uncertainty</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Incomplete Conceptualizations</td>
<td>Pollack (2003)</td>
<td>Uncertainty due to the incomplete conceptualization of the phenomenon</td>
</tr>
</tbody>
</table>

*Note: *Buck’s (2014) use of conceptual uncertainty is different from the conceptual uncertainty category presented in this table.
Because of the inclusion of engineering practices in the NGSS, tasks involving engineering design are becoming increasingly present in K-12 science classrooms and utilized as a way to teach important science concepts (Malkiewich & Chase, 2019). Students engaged in tasks of a design nature might experience uncertainty about their design solution (i.e., the design’s feasibility, practicality, or effectiveness), in addition to the different types of scientific uncertainty. For the purpose of this study, I term this type of uncertainty as design-related uncertainty. Students often can resolve design-related uncertainty through immediate testing and direct observation of the result. In contrast, scientific uncertainty related to generation of new scientific knowledge is more complex and requires a level of inference to be resolved.

*Frameworks in studies of scientific uncertainty.* Thus far, researchers (e.g., Buck et al., 2014; Metz, 2004; Schroeder et al., 2018) have typically used two-dimensional frameworks to ground their investigations of students’ comprehension of scientific uncertainty, with one dimension focusing on the students’ conceptualizations of scientific uncertainty and the other dimension focusing on students’ beliefs about the nature of knowledge in science (Sandoval et al., 2016). The second dimension typically illuminated students’ beliefs and understanding of scientific knowledge as certain and unchangeable, at the lower levels of epistemic cognition, and scientific knowledge as flexible, tentative, and evolving at higher levels (e.g., Buck et al., 2014).

Several researches grounded their conceptualizations of the dimensions of scientific uncertainty in the types of uncertainty evident in the investigative work of scientists (Kirch, 2010) and students (Kirch, 2010; Metz, 2004). Metz (2004) drew on 2nd- and 4th-graders’ reasoning about uncertainty encountered during student-designed investigations of insect behavior and conceptualized a framework consisting of five concentric spheres of scientific uncertainty. In Metz’s framework, the five spheres of scientific uncertainty are: “how to produce
the desired outcome as uncertain, data as uncertain, trend identified as uncertain, generalizability of the trend as uncertain, and theory that best account for the trend as uncertain” (Metz, 2004, p. 241). The uncertainty about producing desired outcome refers to students’ expressions of a lack of knowledge about how to elicit the desired behavior of the insects under study (i.e., chirping, movement). Data uncertainty sphere refers to students expressing distrust in their data (i.e., acknowledging possibility of error). Trend uncertainty refers to students considering the trend they have identified in their data as questionable. Uncertainty about trend generalizability refers to students expressing concern about the extent to which the findings would apply to other insects. The theory uncertainty sphere refers to students’ doubt about the adequacy of the formulated explanation about the observed insect behaviors. Metz conceptualized uncertainty about producing the desired outcome as the innermost, the least sophisticated, sphere of uncertainty, and the uncertainty about theory that best describes the observed trend as the outermost, and the most sophisticated sphere.

This framework, stemming from students’ conceptualizations of uncertainty, has been adopted and adapted by other researchers for classroom studies of scientific uncertainty (e.g., Buck et al., 2014; Schroeder et al., 2018). One significant adaptation of Metz’s (2004) framework is Buck et al. (2014) addition of personal uncertainty as a replacement for Metz’s innermost sphere related to the uncertainty of producing the desired outcome. Buck and colleagues defined personal uncertainty as students’ uncertainty about their own performance, expressed as a lack of confidence in their knowledge, skills, or self-efficacy. Although this definition is somewhat convoluted because the authors made no effort to distinguish between confidence and self-efficacy, it is important that the authors recognized the voicing of personal uncertainty as a first step toward articulation of scientific uncertainty. In their conceptualization
of personal uncertainty, Buck and colleagues focused on confidence, which is a global personal characteristic, whereas self-efficacy refers to people’s beliefs in their capability to organize and execute actions necessary to achieve desired performance in a particular task or a discipline (Zimmerman, 2000). The other three spheres in Buck et al.’s four sphere framework are: (a) empirical uncertainty, which corresponds to Metz’s (2004) data sphere; (b) signal uncertainty, which indicates uncertainty related to the trend in the data, and combines Metz’s third and fourth sphere; and (c) conceptual uncertainty, which corresponds to Metz’s sphere of uncertainty about theory. Inclusion of personal uncertainty in the framework makes explicit that it is not a deficit but a resource that the participants in scientific inquiry use to guide their investigations into the sphere of scientific uncertainty they believe to be in need of evaluation and assessment.

Some of the researchers (e.g., Buck et al., 2014; Metz, 2004; Schroeder et al., 2018) who analyzed students’ understandings of scientific uncertainty, incorporated the dimension of epistemic cognition into their frameworks, operationalizing it as epistemic understandings or epistemological stances about the nature of scientific knowledge and role of uncertainty in its creation. Whereas various models of epistemic cognition exist in the literature (e.g., Chinn, Buckland, & Samarapungavan, 2011; Hofer & Pintrich, 1997; D. Kuhn, Cheney, & Weinstock, 2000; W. G. Perry, 1970; Schommer-Aikins, 2004), several researchers (Buck et al., 2014; Metz, 2004; Schroeder et al., 2018; C. L. Smith & Wenk, 2006) relied on an early model of epistemology of science by Carey and Smith (1993) to assess students’ understanding of the nature of scientific knowledge. Carey and Smith posited that students’ understanding of the nature of scientific knowledge progresses through increasing levels of sophistication, from knowledge unproblematic, at level 1, through an intermediate level 2, to knowledge problematic, at level 3. However, in empirical studies focused on students’ understanding of scientific
uncertainty this framework was sometimes represented as a dichotomy between the unsophisticated understanding of knowledge as simple, fixed, and certain (i.e., knowledge unproblematic), and the sophisticated understanding of knowledge as complex, evolving, and uncertain (i.e., knowledge problematic). Regardless of the students’ age and grade level, researchers found that the majority of students demonstrated only lower levels (i.e., levels 1 and 2) of understanding of scientific knowledge consistent with knowledge unproblematic (e.g., Buck et al., 2014; Metz, 2004; Schroeder et al., 2018). However, Metz (2004) argued that when students did articulate uncertainty in their own investigations and specified ways to reduce it those articulations were consistent with knowledge problematic epistemological perspective. For example, students who articulated uncertainty related to their data collection reflected on the influence of the observer on the insects, which is reflective of a knowledge problematic stance.

Discourse analysis in studies of scientific uncertainty. Researchers in this strand of research relied on semi-structured interviews with participants (Metz, 2004; Schroeder et al., 2018) and discourse analysis of classroom interactions (Kirch, 2010; Kirch & Siry, 2012) to describe ways in which students think about scientific uncertainty, the ways it enters into the scientific inquiry and the ways to resolve it. Whereas interviews with students enabled researchers to illuminate students’ ways of thinking about scientific uncertainty, its sources, and potential ways to address it, discourse analysis served as a powerful tool to analyze the role of language in bringing the uncertainty to the forefront of participants’ engagement in and with scientific inquiry. Researchers used uncertainty discourse markers (e.g., maybe, might, could, probably, possibly, perhaps) to trace students’ expressions of uncertainty and to illuminate how other participants in classroom discourse responded to them (Buck et al., 2014; Kirch & Siry, 2012). Kirch and Siry (2012) found that students used uncertainty markers to indicate
potentiality (i.e., directing attention to future events, such as planning the investigations),
discernment (i.e., directing attention to past and future events to suggest possible explanations),
and challenge (i.e., expressing skepticism). Kirch and Siry noted that specific modifiers were not
used only for a single function (e.g., maybe was used to express potentiality, discernment, and
challenges and not just potentiality). However, all modifiers were used to express real
uncertainty identified during investigations, and not for the purpose of hedging statements (Kirch
& Siry, 2012). Understanding how students talk about uncertainty is the first step in building
teachers’ ability to recognize uncertainty modifiers and to use them to engage students in
dialogue and inquiry that emphasizes scientific uncertainty as inherently present in scientific
enterprise (Kirch & Siry, 2012).

Furthermore, in a comparative study, Kirch (2010) compared 2nd-grade students’
handling of uncertainty with that of professional scientists and found similarities in the ways that
they talk about uncertainty related to what was done during the investigations, what was
observed, and how the findings were interpreted. Kirch focused her discourse analysis on
conversational structures and their function in the identification and resolution of uncertainty and
generation of scientific knowledge. Scientists and students were using similar conversational
structures of statements followed by questions or challenges. As a first step, both, the molecular
biologists in the labs and students in the classrooms, engaged in conversations to achieve
common understanding about what was done and how it was done during data collection with
the aim of resolving uncertainty related to processes of data collection (Kirch, 2010). These
exchanges, characterized by questions posed by those who were not present during the
investigations (i.e., the principal investigator, the teacher), and both simple and elaborate
answers by the investigators (i.e., biologists and students), served to establish what was known as
well as what remained uncertain (Kirch, 2010). Kirch noted that the teacher played the main role in asking clarifying question about students’ inquiry processes and that students needed help with posing such questions to their peers.

In addition, participants in scientific investigations in both science labs and in the elementary classroom also needed to develop joint understanding and resolve uncertainty about what was observed before they could make any conclusions about investigations (Kirch, 2010). In science classrooms, it was the teacher who asked clarifying questions to establish if what was observed by one student was observed by anyone else, and establish a common ground for interpretation of the findings, whereas in the lab, researchers engaged in dialogue to establish mutual understanding and interpretation of what was observed. Lastly, both scientists and students also engaged in resolving uncertainty about interpretations of their findings. Kirch found that in the science labs, the goal of asking questions was to develop an understanding of different interpretations offered by different scientists, giving much attention to determining the levels of uncertainty in their interpretations. In science classrooms, the teacher asked questions to resolve personal uncertainty before evaluating students’ interpretations.

To summarize, both the scientists and the students needed to resolve uncertainty about methods and processes of data collection, about observations, and about interpretations of the findings (Kirch, 2010). However, scientists engaged in dialogue in order to resolve uncertainty and ultimately identify if new knowledge has been created during inquiry, whereas in the classroom, the teacher was doing the questioning and resolving her personal uncertainty in order to establish the common understanding and offer explanations to the class. Kirch’s (2010) findings about similarities and differences in conversational structures and their function for dealing with uncertainty encountered by the scientists and members of the 2nd-grade science
classroom during their scientific investigations, imply that it is possible and necessary to start engaging science students in authentic scientific practices that use uncertainty as a resource in the science classroom rather than attempting to eliminate it (Kirch, 2010). This study also points to the fact that students need to be adequately scaffolded if they are to engage in resolving the uncertainty on their own through dialogic practices and building of a joint understanding.

Kirch primarily focused on patterns of conversation that emerged when scientists and students were reporting on investigations they carried out independently of others. In contrast, in my study, I will use discourse analysis to investigate how groups of preservice science teachers talk about uncertainty and attempt to navigate through it while they are engaging in collaborative inquiry in science.

Researchers found that even students as young as 2nd grade were able to recognize and articulate scientific uncertainty and its sources in their own investigations and suggest viable ways to reduce it in subsequent inquiries (Kirch, 2010; Metz, 2004). A greater proportion of students in 4th and 5th grade than in 2nd grade showed the ability to articulate scientific uncertainty and propose ways to reduce it (Metz, 2004). However, findings about development of understanding of scientific uncertainty due to natural maturation remain inconclusive. For example, Metz (2004) observed that 4th and 5th graders brought up uncertainty related to the trend identified in data more often than 2nd-graders. Upon a closer examination of the content of students’ science instruction during the previous year and of classroom discussions in the current grade, Metz concluded that the majority of older students participated in a lesson about sampling during the previous school year and that sampling was included in their classroom discussions in the current grade. In contrast, 2nd-graders discussions and instruction did not dedicate attention to sampling (Metz, 2004). Hence, Metz attributed the observed differences not to the natural
maturation in students’ understanding of scientific uncertainty but to the differences in the content of instruction. Similar to Metz’s inconclusive findings about natural maturation in the understanding of scientific uncertainty between 2nd- and 4th- and 5th-graders, Schroeder et al. (2018) found no identifiable trend in differences between 5th-graders and 9th-graders’ conceptualizations of uncertainty and ability to identify sources of it. Hence, although more studies are needed to investigate development of students’ understanding of scientific uncertainty as a result of natural maturation, current evidence suggests that it is the content of instruction that makes a difference.

The main criticisms of these studies are that they were not longitudinal studies. Also, the authors conducted the analysis at the individual student level (Buck et al., 2014; Metz, 2004) even though students worked in small-groups or dyads, and did not consider and report on how groups grappled with uncertainty or how the group dynamics and learning might be affected by it. For example, in her seminal study of scientific investigations of students’ own design, Metz (2004) collected rich data, which included semi-structured interviews, video recordings of the classroom work, and group-created posters, at a level of student dyads, but during the analysis the ideas about uncertainty were attributed to individual students. Thus, there is a gap in research about how groups of learners deal with scientific uncertainty. This gap is important because authentic scientific practice involves work with peers and collective knowledge construction. Hence, comprehensive knowledge about ways learners navigate through scientific uncertainty during collaborative inquiry needs to include knowledge about social practices and processes groups enact.

**Uncertainty orientations and related constructs in psychology literature.** Psychology researchers have a long tradition of studying individual differences related to the ways in which
people deal with uncertainty and ambiguity. The three most prominent conceptualizations from psychology are intolerance of ambiguity (Frenkel-Brunswik, 1949), need for cognitive closure (Webster & Kruglanski, 1994), and uncertainty orientations (Sorrentino & Roney, 2000; Sorrentino, Roney, & Hanna, 1992; Sorrentino, Short, & Raynor, 1984). Whereas there are other related and widely studied constructs, such as intolerance of uncertainty, they have been applied mostly in clinical psychology in studies of anxiety and depression (Rosen, Ivanova, & Knäuper, 2014), so they remain beyond the scope of this paper. In this section, I focus on the three constructs that have been studied in social psychology. I provide a short overview of the first two frameworks, intolerance of ambiguity and need for cognitive closure, and then review the research program on uncertainty orientations in more detail. The first two constructs are relevant because they provide additional information about how people react to uncertainty and ways in which their reactions affect decision making and group dynamics. The third construct, construct of uncertainty orientation, is the one I propose to use for my study because the measures of uncertainty orientation account for both individuals’ ways of dealing with uncertainty and individuals’ way of dealing with certainty, thus making it possible to understand a person’s orientation as uncertainty- or certainty-oriented.

**Intolerance of ambiguity.** Frenkel-Brunswik (1949) introduced the construct of intolerance of ambiguity (IA) based on her studies of children’s adherence to or rejection of prejudice. Frenkel-Brunswik originally conceptualized IA as an emotional and perceptual variable, related to authoritarianism and prejudice. Over time, the construct has evolved and in the current interpretation refers to a person’s propensity for interpreting ambiguous situations as threatening or discomforting (Budner, 1962; Grenier, Barrette, & Ladouceur, 2005). Ambiguous situations are situations that an individual is not able to categorize or structure because the
available cues are insufficient (Budner, 1962). There are three sources of situational ambiguity: (a) novelty, where there are no familiar cues, (b) complexity, where there are many available cues, and (c) insolubility, where cues are conflicting (Budner, 1962). In any of these three types of situations, a person high in IA responds with very specific cognitive, behavioral, and emotional reactions (Grenier et al., 2005). An IA person’s cognitive reaction to an ambiguous situation is to view such situation rigidly, as black or white. Typical behavioral reactions include avoidance and rejection of ambiguous situations (Grenier et al., 2005; Rosen et al., 2014). Emotionally, IA persons respond to ambiguous situations with feelings of discomfort, dislike, uneasiness, anxiety, and anger (Grenier et al., 2005; Rosen et al., 2014).

Grenier et al. (2005) pointed out that intolerance of ambiguity can be distinguished from a similar term, intolerance of uncertainty, by its unique time-orientation on the present moment. Persons high in intolerance of ambiguity are not capable of tolerating “here and now” (Grenier et al., 2005, p. 596) ambiguity situations and interpret them as a threat. In contrast, people who are intolerant of uncertainty focus on ambiguity of future events (Grenier et al., 2005). In those cases, a threat, which is coming from some future ambiguous situation, results in excessive worrying and anxiety (Buhr & Dugas, 2006), making this construct more salient for clinical studies (Grenier et al., 2005). Additionally, it is important to notice that some researchers (e.g., DeRoma, Martin, & Kessler, 2003; Jessani & Harris, 2018; Kajs & McCollum, 2009; Steenkamp & Wessels, 2014) used the term tolerance of ambiguity, which Budner (1962) defined as “the tendency to perceive ambiguous situations as desirable” (p. 29). However, regardless of the whether they focus on intolerance or tolerance of ambiguity, these researchers contribute to the same area of scholarship.
Despite the long-standing research tradition and interest that the construct of intolerance/tolerance of ambiguity aroused in various fields, measures, which are mostly self-report questionnaires, used by the researchers on intolerance of ambiguity have been plagued by conceptual disparities and psychometric weaknesses (McLain, 2009). Although multiple researchers have offered different conceptualizations of the term tolerance/intolerance of ambiguity and designed new measures (e.g., Durrheim & Foster, 1997; Herman, Stevens, Bird, Mendenhall, & Oddou, 2010; McLain, 1993, 2009), the 16-item scale of tolerance-intolerance of ambiguity (TIA) designed by Budner in 1962 remains one of the most popular scales in this area of scholarship (Furnham & Marks, 2013; Grenier et al., 2005). The discussions about the construct of tolerance/intolerance of uncertainty and related measures are beyond the scope of this paper (see Durrheim & Foster, 1997 and Furnham & Marks, 2013 for details). Due to this evident lack of convergence in the field regarding the definition and conceptualization of the terms and related measures, I will not be using the construct of tolerance/intolerance of ambiguity for my study. Hence, in the next section I provide only a brief and high-level overview of main research directions in research on intolerance/tolerance of ambiguity.

Researchers have studied intolerance of ambiguity in various applied fields such as organizational behavior (e.g., Chen & Hooijberg, 2000; Ma & Kay, 2017), management (e.g., DeBusk, Killough, & Brown, 2009; Gupta & Govindarajan, 1984), medicine (e.g., Geller, Tambor, Chase, & Holtzman, 1993; Hancock, Roberts, Monrouxe, & Mattick, 2015; Weissenstein, Ligges, Brouwer, Marschall, & Friederichs, 2014), and education (DeRoma et al., 2003; Tapanes, Smith, & White, 2009). What all these fields have in common is that practitioners in each often operate in ambiguous situations that necessitate creativity, flexibility, and complex problem solving, as well as openness to diversity and new cultures. In such
situations, intolerance of ambiguity evidenced in cognitive rigidity, anxiety, and avoidance behaviors becomes maladaptive (DeRoma et al., 2003). Thus, it is important to be able to discern practitioners’ tolerance of ambiguity (Geller, 2013; Hancock et al., 2015; Kajs & McCollum, 2009) in order to help them become more proficient with handling it and more effective in their jobs (Stoycheva, 2003).

Empirical evidence seems to suggest that individual’s tolerance or intolerance of ambiguity impacts his or her information seeking and decision making (DeBusk et al., 2009; Geller et al., 1993; Gupta & Govindarajan, 1984; Yurtsever, 2001) as well as openness and support for diversity (Bakalis & Joiner, 2004; Chen & Hooijberg, 2000; Tapanes et al., 2009). People who are intolerant of ambiguity tend to perceive ambiguous situations as sources of threat, and react with anxiety and avoidance to the insufficient or contradictory cues in the environment (Stoycheva, 2003; Yurtsever, 2001). They attempt to reduce ambiguous situations to simple and familiar cues and rigidly adhere to what they already know, leading to suboptimal solutions for the problem at hand (Stoycheva, 2003). In contrast, people who are tolerant of ambiguity have more adaptive responses and emotional reactions to it, and are able to perceive ambiguous situations more realistically (Stoycheva, 2003). They are able to handle ambiguity with flexibility and without distorting or omitting complex cues (Stoycheva, 2003).

Tolerance of ambiguity seems to be one of the defining characteristics of entrepreneurs (Koh, 1996; Wagener, Gorgievski, & Rijsdijk, 2010) and managers who operate in growing business units (Gupta & Govindarajan, 1984). In contrast, accountants tend to be more intolerant of ambiguity than other professionals (Steenkamp & Wessels, 2014). Researchers (Budner, 1962; Geller et al., 1993) found that even doctors’ choice of specialty might be influenced by their tolerance of ambiguity, with lower tolerance of ambiguity individuals choosing to specialize in
surgery (i.e., high structure specialty) and higher tolerance of ambiguity individuals specializing in psychiatry (i.e., low structure specialty). Others (e.g., Hancock et al., 2015) did not find a significant relationship between intolerance of ambiguity and doctors’ choice of specialty, although they did find lower tolerance of ambiguity for surgeons than for other specialists.

For people high in intolerance of ambiguity, need for structure might lead to oversimplifying of available information (DeBusk et al., 2009; Geller et al., 1993) or even misrepresentation of it (Yurtsever, 2001). Executives intolerant of ambiguity seemed to rely more on performance indicators, such as balanced score card (BSC), and agreed that BSC information is sufficient to make the evaluation of performance than executives who were ambiguity tolerant (DeBusk et al., 2009). At the same time, executives who relied on BSC more were also more confident in their evaluations of the business-unit performance (DeBusk et al., 2009). In a recent study, Jessani and Harris (2018) found that people low in ambiguity tolerance had a tendency to deny climate change, and the agentic role of humans in causing as well as in addressing climate change. Jessani and Harris also confirmed findings from previous studies (e.g., Jost et al., 2007; Sidanius, 1978) that people low in tolerance of uncertainty tend to have conservative political views. People who have high intolerance of ambiguity were less likely to participate in diversity-oriented programs that would expose them to cultures and people different from themselves (Bakalis & Joiner, 2004; Chen & Hooijberg, 2000) and wanted to be informed about cultural differences they might encounter beforehand (Tapanes et al., 2009). In contrast, medical students who were tolerant of ambiguity showed less decline in their attitudes toward underserved populations than their counterparts who were intolerant of ambiguity (Wayne et al., 2011).
In educational settings, adherence to structure was evident in the preference of undergraduate and graduate students with low tolerance of ambiguity for clear course structure in terms of specified deadlines and exam dates (DeRoma et al., 2003). Such students also exhibited anxiety related to test items that required application of knowledge and had more than one possible answer (DeRoma et al., 2003). However, importantly, there are teaching methods, such as case study methods, that can improve students’ tolerance of ambiguity by simulating similar psychological states they are likely to experience in real-life situations (Banning, 2003). In summary, findings from research on tolerance or intolerance of ambiguity indicate that person’s perception of ambiguous situations and subsequent reactions shape personal beliefs, such as political preferences, as well as information seeking and decision-making processes, ranging from career choices to the preference for learning environments.

**Need for cognitive closure.** The need for cognitive closure is a desire to reach a definitive, non-specific answer on some open issue or question in order to avoid uncertainty, confusion and ambiguity (Kruglanski & Webster, 1996; Roets, Kruglanski, Kossowska, Pierro, & Hong, 2015; Webster & Kruglanski, 1994). Desire for non-specific closure indicates person’s preference for any answer that is definitive and provides closure, as opposed to the desire for specific closure, which would indicate person’s desire for a particular, specific answer (Webster & Kruglanski, 1994). For example, a teacher grading tests is interested in assigning the most adequate grade to each student regardless of what the specific grade may be (i.e., nonspecific closure), whereas a student who took the tests hopes to earn an A (i.e., specific closure). As this example indicates, in educational settings, a specific closure may be very similar to and difficult to discern from an achievement goal. Need for closure is a motivational variable related to the
“person’s motivations related to information processing and judgement” (Webster & Kruglanski, 1994, p. 1049).

Need for closure is conceptualized as varying along a continuum with strong need for closure at one end and strong need to avoid closure at the other end (Kruglanski & Webster, 1996; Webster & Kruglanski, 1994). Individuals with a strong need for closure are motivated to eliminate uncertainty and obtain closure, thus they engage in quick and simplistic decision formulations based on limited evidence (Kossowska & Bar-Tal, 2013; Kruglanski & Webster, 1996; Rydzewska, von Helversen, Kossowska, Magnuski, & Sedek, 2018; Webster & Kruglanski, 1994). On the other hand, individuals who have a strong resistance to closure are motivated to maintain uncertainty and avoid definitive closure, thus they suspend judgment as they engage in systematic evaluation of available options resulting in more complex and flexible decision making (Kossowska & Bar-Tal, 2013; Kruglanski & Webster, 1996; Rydzewska et al., 2018; Webster & Kruglanski, 1994).

The need for closure arises from two different tendencies: (a) the urgency tendency, which is the tendency to quickly seize on information that could lead to closure, and (b) the permanence tendency, which is the tendency to freeze the existing knowledge and protect it from contradictory knowledge (Kruglanski & Webster, 1996). Hence, both tendencies serve the function of “gatekeeping” (Roets et al., 2015, p. 225). The urgency tendency, through the process of seizing, helps eliminate lack of closure, and the permanence tendency, through the process of freezing, keeps lack of closure from re-occurring (Roets et al., 2015).

Webster and Kruglanski (1994) posited that need for closure is a latent variable with five major surface manifestations: (a) preference for predictability; (b) preference for order and structure, (c) discomfort with ambiguity; (d) decisiveness; and (e) closed-mindedness. Manifest
variables in personality psychology are the traits that can be measured (i.e., by a test or a survey), and that, if they correlate, combine to describe a latent variable (McMartin, 2016). A latent variable, such as need for closure, thus, is a broader personality trait that cannot be assessed directly but can be described through its surface manifestations (McMartin, 2016). The original need for closure scale by Webster and Kruglanski was later revised by Roets and Van Hiel (2007), who further specified that decisiveness was referring to the need for decisiveness, described as the person’s motivation to obtain quick, decisive answers, and not to a person’s ability to be decisive (see Roets et al., 2015; Roets & Van Hiel, 2007). Empirical evidence suggests that for high need for closure individuals, absence of closure is stressful and causes increased blood pressure, elevated heart rate, and increased galvanic skin response (Roets & Van Hiel, 2008).

Whereas researchers (Roets & Van Hiel, 2007; Webster & Kruglanski, 1994) designed the need for closure scale to measure a person’s stable, trait-like motivational tendency, need for closure can be also induced as a function of a situation (Webster & Kruglanski, 1994). Regardless of whether the researchers assessed need for closure using the dispositional measure or by inducing it through situational manipulation, empirical results were convergent (e.g., De Grada, Kruglanski, Mannetti, & Pierro, 1999; Kruglanski, Shah, Pierro, & Mannetti, 2002; Pierro, Mannetti, De Grada, Livi, & Kruglanski, 2003). Kruglanski and colleagues (e.g., Kruglanski & Webster, 1996; Roets et al., 2015; Webster & Kruglanski, 1994) posited that the need for closure is proportionate to the perceived benefits of attaining closure, costs of lacking closure, or both. Hence, situations in which information processing becomes more difficult or uncomfortable heighten the need for cognitive closure (Kruglanski & Webster, 1996).
For example, under time pressure (e.g., Bukowski, von Hecker, & Kossowska, 2013; Heaton & Kruglanski, 1991; Kruglanski & Freund, 1983; Kruglanski et al., 2002), ambient noise (Kruglanski & Webster, 1991; Kruglanski, Webster, & Klem, 1993), or when dealing with a dull, uninteresting task (Webster, 1993), perceived benefits of achieving closure are high; hence, the need for closure is heightened. Reaching closure provides a way out of a situation that is perceived as costly and unpleasant (Bukowski et al., 2013). In such situations, persons high in the need for closure succumb to primacy effects, seizing upon the information that was presented early on to reach quick judgements and being less sensitive to the relevant information presented later (Heaton & Kruglanski, 1991; Kruglanski & Freund, 1983). In high need for closure situations induced by time pressure, participants increasingly relied on heuristic processing such as relying on stereotypes based on ethnicity or nationality to reach judgements about others (Bukowski et al., 2013; Kruglanski & Freund, 1983), and failed to integrate relevant diagnostic information, inconsistent with previous categories, that were introduced late in the task and required analytic thinking (Bukowski et al., 2013). Thus, in situations that increased need for closure, individuals seized on the information that was readily available in their minds, and had a tendency to reach quick but wrong decisions (Bukowski et al., 2013; Heaton & Kruglanski, 1991; Kruglanski & Freund, 1983; Richter & Kruglanski, 1998).

In situations when there is no prior knowledge available to help with decision making, researchers have observed a different pattern of information seeking and decision making. People high in need for closure spent more time searching for information than people low in need for closure (Jaśko, Czernatowicz-Kukuczka, Kossowska, & Czarna, 2015; Vermeir, Van Kenhove, & Hendrickx, 2002). Whereas Vermeir et al. (2002) investigated consumer behavior in low-involvement purchasing decisions (i.e., routine buying decisions of household products),
Jaśko et al. (2015) found the same information seeking behavior in a task where the cost of closure was high. Jaśko and colleagues elucidated that when the perceived costs of closure are high and the task does not have a clear rule for decision making, people who are high in need for closure engaged in longer searching for information than people who are low in need for closure. If there was a reliable decision-making strategy suggested within the task, then, consistent with other findings from this area of scholarship, people high in need for closure used the available rule to make decisions and quickly obtain closure (Jaśko et al., 2015).

Need for closure has significant influence on groups’ information seeking and decision making processes (e.g., De Grada et al., 1999; Kruglanski & Webster, 1991; Livi, Kruglanski, Pierro, Mannetti, & Kenny, 2015; Pierro et al., 2003; Pierro, Sheveland, Livi, & Kruglanski, 2015). Kruglanski et al. (2006) used the term *group centrism* to refer to the social effects of need for closure in intra and intergroup settings. Group centrism refers to patterns of behavior characteristic of the high need for closure groups that include a preference for autocratic group leaders, in-group favoritism, aversion toward out-groups, pressure to conform to opinion uniformity, rejection of opinion deviates, resistance to change, and perpetuation of group norms (Kruglanski et al., 2006; Roets et al., 2015). In essence, groups serve as providers of readily available knowledge for the group members (Kruglanski et al., 2006). Group members high in the need for closure seize on the available knowledge, showing in-group favoritism and rejection of out-groups (Kruglanski et al., 2002). High need for closure groups had a tendency to develop autocratic leadership structure, characterized by one group member’s dominance in discussion, and greater influence on the group’s decision making (De Grada et al., 1999; Pierro et al., 2003). Under high collective need for closure, groups negatively evaluated group members with different opinions (i.e., opinion deviates) and positively evaluated members with conforming
opinions (Kruglanski & Webster, 1991). In a series of three studies conducted in natural and experimental settings, Livi et al. (2015) found that groups high in need for closure (i.e., groups composed of members high in closure) showed closer adherence to group norms than groups low in need for closure, thus exhibiting greater cultural stability across generations. In a work environment, a fit between an employee’s and group’s need for closure (i.e., high need for closure person in a high need for closure group or low need for closure person in a low need for closure group) translated into better job performance and stronger identification with the group (Pierro et al., 2015). In my study, research on need for closure will help inform my thinking about group dynamics and information-seeking and decision-making processes, especially if signs of group centrism (i.e., other regulation) were to emerge in collaborative groups.

**Uncertainty orientations.** Sorrentino et al. (1984) and Sorrentino and Short (1986) conceptualized the construct of uncertainty orientations by drawing upon research by Kagan (1972) and Rokeach (1960). As discussed in Chapter I, Kagan (1972) posited that the motivation to resolve uncertainty is one of the four primary human motivations. Kagan conceptualized uncertainty as originating from a dissonance between two ideas, an idea and an experience, an idea and a behavior, or from the inability to predict the future. Rokeach (1960) distinguished between closed-minded individuals, who feel threatened by uncertainty and new beliefs hence orienting toward familiar and predicable situations, and open-minded individuals, who do not feel threatened by uncertainty and orient toward new information and new beliefs. Sorrentino and colleagues posited that both motivational and cognitive influences shape the individual differences in uncertainty orientations and how people behave in situations of varying uncertainty (Sorrentino & Roney, 2000; Sorrentino, Smithson, Hodson, Roney, & Marie Walker, 2003). More specifically, the construct of uncertainty orientation refers to the individual
differences in information processing that become evident when individuals approach situations of varying degrees of uncertainty (Shuper & Sorrentino, 2004).

**Model of uncertainty orientations.** According to the Sorrentino and colleagues’ (Shuper, Sorrentino, Otsubo, Hodson, & Walker, 2004; Sorrentino et al., 2003) model of uncertainty orientations (Figure 2.1), when the situation is uncertain, uncertainty-oriented (UO) individuals become actively engaged, cognitively and behaviorally, and are motivated to work to resolve the uncertainty. This tendency of UO individuals to approach uncertainty increases in situations of personal relevance and UO individuals strive to resolve uncertainty by learning new

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<th>Personal relevance</th>
<th>Resultant engagement</th>
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<td>Uncertainty oriented</td>
<td>Uncertain situation</td>
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<td>Active Engagement + (Matched situation)</td>
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information about themselves or the salient aspects of the environment. In contrast, when the situation is characterized as certain, UOs react passively, becoming disengaged. Certainty-oriented (CO) individuals show the opposite tendencies. They are motivated by situations of certainty, which lead the CO individuals to become actively engaged and strive to maintain certainty and clarity. This tendency of CO individuals to avoid or ignore uncertainty and orient toward certainty increases in situations of personal relevance when there is nothing novel to be learned about the self or the environment. Conversely, CO individuals react passively and become disengaged in uncertain situations. Additionally, in situations that match their personal uncertainty orientation, UO and CO individuals experience active positive (e.g. excitement, happiness) or active negative emotions (e.g. feeling alarmed or afraid). When there is a mismatch between their personal uncertainty orientation and the situation, for example UO individuals in certainty situation or CO individuals in uncertain situations, people experienced passive positive (e.g., calm, relaxed) or passive negative emotions (e.g., depressed, bored; Shuper & Sorrentino, 2004; Sorrentino & Roney, 2000). Similar to the need for cognitive closure (Webster & Kruglanski, 1994), uncertainty orientations are conceptualized to fall along a continuum, with UO individuals at one end and CO individuals at the other end (Sorrentino & Short, 1986).

*Measurement of uncertainty orientations.* The model of uncertainty orientation stems from a program of empirical research that spans more than three decades. Researchers (e.g., Brouwers & Sorrentino, 1993; Sorrentino, Bobocel, Gitta, Olson, & Hewitt, 1988; Sorrentino & Hewitt, 1984; Sorrentino et al., 1995; Sorrentino et al., 1984) initially focused on characterizing behaviors of people with differing uncertainty orientations. To this aim, Sorrentino and colleagues (e.g., Sorrentino & Hewitt, 1984; Sorrentino et al., 1984) developed a measure of individual uncertainty orientation that is a composite of two independent measures, a measure
called \textit{n}Uncertainty, used to infer the person’s need to resolve uncertainty, and the Cherry and Bryne (1977) acquiescence-free measure of authoritarianism, used to infer person’s need to maintain certainty. I provide a detailed description of the measures of uncertainty orientation as well as the related procedures for administering the measures in Chapter III, so I describe them only briefly in this section.

The measure of \textit{n}Uncertainty is the thematic apperception test (TAT). It is akin to the measure called \textit{n}Achievement, which motivation researchers have used to infer motivation to succeed, based on the theory of achievement orientation by Atkinson and colleagues (Atkinson & Raynor, 1974; McClelland, Atkinson, Clark, & Lowell, 1958). In the TAT, researchers typically provide participants with a cue (e.g., a picture, a sentence lead) and participants produce a narrative response to it (Langan-Fox & Grant, 2006). Then, researchers examine participants’ narrative responses for imagery that reveals participants’ underlying motives, concerns, and the way they perceive the world (Langan-Fox & Grant, 2006). For measure of \textit{n}Uncertainty, participants were provided with four one-sentence leads and asked to write a short story in response to each story lead (Sorrentino, Hanna, & Roney, 1992; Sorrentino, Roney, et al., 1992). Next, each story was scored for the presence of uncertainty imagery if the participant included references to the goal of actively approaching and resolving uncertainty. If the researchers determined that the story contained doubtful uncertainty imagery, it received a zero score. If the story contained unrelated imagery, it received a score of -1. If the researchers determined that the story contained uncertainty imagery, they assigned it a score of one for the presence of uncertainty imagery and then they scored it further for 10 subcategories: (a) stated need to master uncertainty; (b) instrumental activity; (c) positive goal anticipation; (d) negative goal anticipation; (e) blocks in the person; (f) blocks in the world; (g) nurturant press; (h)
positive affective state; (i) negative affective state; and (j) thema. Hence, a possible range of scores for each story was between -1, when there is no uncertainty imagery present in the story, to 11, when there is uncertainty imagery present as well as all 10 subcategories. The final \( n \)Uncertainty score for each individual is calculated by summing together scores for all four stories.

Sorrentino and colleagues posited that the second component, based on Cherry and Byrne’s (1977) measure of authoritarianism, could be used to assess the need to maintain certainty, because people who score high on this measure tend to prefer certain and familiar situations (Sorrentino, Roney, et al., 1992). The measure has 21 items, rated on 6-point scales ranging from “-3, I disagree very much, to 3, I agree very much” (Sorrentino, Roney, et al., 1992, p. 422). According to Sorrentino, Roney, et al. (1992), this measure has high test-retest reliability as well as internal consistency, both above .86. The two measures are independent; in other words, it is possible for a person to receive a high score on both measures, low scores on both measures, or high scores on one measure and low on the other.

The resultant uncertainty orientation score is calculated by transforming both the \( n \)Uncertainty and authoritarianism score into z-scores and subtracting authoritarianism z-scores from \( n \)Uncertainty z-scores (Sorrentino, Roney, et al., 1992). Participants whose scores fall in the upper third of the continuum are classified as UO and those with scores in the lower third are classified as CO. Sorrentino and colleagues focus on categories of UO and CO individuals in their studies, because the behavior of the persons who are classified in the middle of the scale tends to be inconsistent and cannot be predicted (Hodson & Sorrentino, 1999; Sorrentino & Short, 1977). Sorrentino and Short (1977) used the term “the mysterious moderates” (p. 478) to capture characteristics of the people with moderate uncertainty orientation. In this study, I
created a mixed group with two moderates and two participants who had the most extreme UO and CO uncertainty orientation scores.

The main findings from the empirical studies indicated that UO individuals have a positive orientation toward uncertain situations and are motivated to resolve uncertainty by focusing on what can be discovered and learned about themselves and their environment from the uncertain situations (Brouwers & Sorrentino, 1993; Roney & Sorrentino, 1995b; Sorrentino & Hewitt, 1984). In uncertain situations, UO individuals are motivated to think effortfully and process information systematically (Hodson & Sorrentino, 2003; Shuper & Sorrentino, 2004; Sorrentino et al., 1988), choosing effective strategies, such as relaying on most diagnostic tests in order to get the most useful information and resolve uncertainty about their health or ability (Brouwers & Sorrentino, 1993; Sorrentino & Hewitt, 1984). The most important situations for UO individuals are uncertain situations, so person’s desires and fears will be the greatest in situations of uncertainty (Sorrentino et al., 1984).

CO individuals, on the other hand, orient toward what is certain, known and familiar, and strive to maintain current clarity by avoiding or ignoring uncertainty (Sorrentino & Hewitt, 1984; Sorrentino et al., 1995). In uncertain situations, CO individuals resort to using heuristics, which are shortcuts for judgement and decision-making (Hodson & Sorrentino, 1997, 2001; Sorrentino et al., 1988; Sorrentino et al., 1995), such as relying on the group leader’s opinion instead of formulating one’s own (Hodson & Sorrentino, 1997). Additionally, in uncertain situation, CO individuals tend to use ineffective strategies and seek to preserve present clarity by avoiding learning new information about themselves or their environment (Brouwers & Sorrentino, 1993; Sorrentino & Hewitt, 1984). In contrast, in situations that provide familiarity (e.g., situations of low personal relevance, that do not involve uncertainty about self or the environment), CO
people are motivated to think effortfully and systematically to maintain clarity (Shuper & Sorrentino, 2004; Sorrentino et al., 1988). The most relevant situations for CO individuals are situations of high certainty and person’s fears and desires will be the greatest in situations of certainty (Sorrentino et al., 1984). No gender differences were found as a function of uncertainty orientation and achievement motivation (Sorrentino & Hewitt, 1984; Sorrentino et al., 1984).

Differences in individual performance due to the person’s achievement motivation (success-orientation vs. failure-threatened) occur in situations that match person’s uncertainty orientation (Study 1, Sorrentino et al., 1984). A UO person, who is also success-oriented, would be the most positively motivated to succeed in uncertain situations. Likewise, a UO individual, who is failure-threatened, would be the most threatened in uncertain situations, and motivated to avoid failure. In contrast, in a mismatched situation, a UO individual in a certainty situation would experience passive negative reactions such as boredom and lack of motivation. Thus, the theory of uncertainty orientation aims to explain not only which people have the propensity to orient toward uncertainty or away from it, but also in which situations they are likely to engage in careful information processing or to employ heuristics for decision making (Hodson & Sorrentino, 1999; Sorrentino & Roney, 2000).

With the exception of a study by Huber, Sorrentino, Davidson, Epplier, and Roth (1992), researchers (e.g., Brouwers & Sorrentino, 1993; Roney & Sorrentino, 1995b; Sorrentino et al., 1988; Sorrentino, Hewitt, & Raso-Knott, 1992; Sorrentino et al., 1995; Sorrentino et al., 1984) carried out the majority of initial empirical studies of uncertainty orientations with adult participants in Western cultures (e.g., Canada), causing concern about generalizability of the theory of uncertainty orientations. To address those concerns, researchers have turned their attention to cross-cultural studies (Shuper et al., 2004; Sorrentino et al., 2008; Szeto, Sorrentino,
Yasunaga, Kouhara, & Lin, 2011) and studies with young students (Sorrentino, Szeto, Chen, & Wang, 2013; Wang, Chen, Sorrentino, & Szeto, 2008). This line of research draws on works by Hofstede (1980) and Triandis (1989) about differences between loose and tight cultures. “Loose cultures” (Triandis, 1989, p. 510) encourage individualism, freedom, and deviation from norms, whereas “tight cultures” (Triandis, 1989, p. 510) rely on collectivism, and emphasize strict adherence to the rules in order to maintain predictability. Researchers (Shuper et al., 2004; Sorrentino et al., 2008; Szeto et al., 2011) posited that in a collectivist, tight culture (e.g., Japan), a normative way of dealing with uncertainty is avoiding it and adhering to certainty. In contrast, in an individualistic, loose culture (e.g., Canada), a normative way of dealing with uncertainty is actively approaching it and resolving it.

Researchers found that Canadian college students were more uncertainty-oriented than their Japanese peers (Shuper et al., 2004; Szeto et al., 2011). Students whose uncertainty orientation matched their culture’s dominant way of dealing with uncertainty (i.e., UO individuals in Canada and CO individuals in Japan), experienced more positive and active emotions (e.g., enthusiasm, alertness, pride), and less negative and passive emotions (e.g., boredom, sluggishness; Sorrentino et al., 2008). Students also showed less unrealistic optimism, a “self-enhancing process reflecting the bias that one’s chances in life are better than one’s peers” (Shuper et al., 2004, p. 463). Additionally, such students self-reported a better fit with their classroom learning environment than did students whose uncertainty orientation did not match the uncertainty orientation of their culture (Szeto et al., 2011). Consistent with previous findings about the ways in which uncertainty orientation interacts with achievement related motives (e.g., Sorrentino & Roney, 1986; Sorrentino et al., 1984), success-oriented UO individuals in Canada and CO individuals in Japan had higher course grades than their failure-
threatened peers. This indicates that people became actively engaged and were best motivated to perform in situations that matched their individual uncertainty orientation (Szeto et al., 2011).

Findings from two studies with elementary school students in China and Canada focused on the importance of the match between a person’s uncertainty orientation and classroom fit are similar (Sorrentino et al., 2013; Wang et al., 2008). As in Canada, culturally dominant ways of dealing with uncertainty in urban centers in China are active discovery and resolution of uncertainty (Sorrentino et al., 2013; Wang et al., 2008). UO children in China and Canada had higher teacher-, peer-, and self-ratings on social competencies (e.g., leadership, ease of making friends) as well as self- and teacher-reported ratings of school related competencies and academic achievement (e.g., language skills, math abilities) than CO children (Sorrentino et al., 2013; Wang et al., 2008). Teachers also reported UO children as having fewer learning problems and issues with loneliness than their CO peers (Sorrentino et al., 2013; Wang et al., 2008). Thus, as Sorrentino et al. (2013) pointed out, the desire to explore and learn new things in novel situations, typical of the UO individuals, might be perceived as an indication of better adjustment for such children.

Uncertainty orientations and group learning. Collaborative learning methods are especially oriented toward exploration and self-discovery, so it is somewhat perplexing that only a few researchers (Hänze & Berger, 2007; Huber, 2003; Huber et al., 1992) have investigated the construct of uncertainty orientation in the context of collaborative learning in the classroom, carrying out fewer than ten studies. Researchers (Hänze & Berger, 2007; Huber, 2003; Huber et al., 1992) hypothesized that group members’ individual differences in uncertainty orientations will influence their preferences for and performance in collaborative settings. In a series of four empirical studies, Huber et al. (1992) studied diverse populations of university, secondary, and
middle school students from Canada, Germany, and Iran and preservice teachers from Canada. The authors found that UO students from all three countries preferred cooperative learning to competitive and individual learning more than their CO counterparts (Study 1, Huber et al., 1992). The cooperative learning method used in this study was Aronson’s jigsaw method (Aronson, Blaney, Stephan, Sikes, & Snapp, 1978) in which students individually learn about certain aspects of the problem and then share their findings with the group. In small-group situations, UO students perceived the group climate as positive and felt that they had influence over their groups’ learning (Huber, 2003; Huber et al., 1992). Moreover, UO students performed significantly better under cooperative learning conditions than CO students, who performed better under traditional teaching methods (Huber, 2003; Huber et al., 1992). Huber (2003) noted that the differences in decision making between homogenous groups consisting only of UO or only of CO students were the most apparent in ill-structured tasks, and diminished as the tasks became more structured. Whereas Huber et al. (1992) in Study 3 found that UO students had higher academic performance scores in collaborative learning setting than CO students, Hänze and Berger (2007) were unable to replicate this finding, or show that uncertainty orientation contributed to deeper level processing or intrinsic motivations. Hence, more classroom studies are needed to illuminate how learners’ uncertainty orientations influence collaborative group work and learning. In Study 4, Huber et al. (1992) investigated how preservice teachers behave as collaborative learners and found that, consistent with the authors’ expectations, UO teachers preferred cooperative learning methods, were more agreeable with their team members, and elaborated on methods used to reach consensus in their groups. In contrast, CO teachers were less likely to agree with their team members, but subsequently reported that there was no need to engage in reaching the consensus (Huber et al., 1992).
Group dynamics. Group members’ uncertainty orientations affect group processes and influence group dynamics (Hodson & Sorrentino, 1997, 2001; Huber et al., 1992; Sorrentino & Roney, 2000). Hodson and Sorrentino (1997) investigated how group members’ individual differences in uncertainty orientations contribute to the groups’ tendency to engage in groupthink, which is a group process defined as "the deterioration of mental efficiency, reality testing, and moral judgment that results from in-group pressures" (Janis, 1982, p. 9). According to Janis (1982), groupthink influences both group processes as well as the final decision reached by the group, and is characterized by biased decision making, during which the group abandons rational thinking. Hodson and Sorrentino (1997) found that CO groups tended to succumb to groupthink more than UO groups, especially under conditions of closed leadership. Closed leaders state their position early on, thus establishing group norms that influence the group’s information sharing and decision making. In contrast, open leaders avoid stating their opinion early on in the discussion and encourage an open exchange of ideas, thus increasing the probability that new and non-confirming information will be disclosed by the group members. Groupthink in CO groups also was stronger when group cohesion was high vs. low.

Summary. According to Kagan (1972) the motivation to resolve uncertainty is one of the four primary human motivations. At the intrapersonal level, uncertainty is experienced as an affective state, originating from detected dissonance between the two ideas, an idea and an experience, an idea and a behavior, or from the inability to predict the future. Psychology researchers (Grenier et al., 2005; Kruglanski & Webster, 1996; Roets & Van Hiel, 2008; Sorrentino & Roney, 2000; Webster & Kruglanski, 1994) have emphasized that many people experience stress, discomfort, and uneasiness in uncertain situations. Of the three most prevalent psychology constructs that focus on individual differences in dealing with uncertainty,
uncertainty orientations theory is unique in its emphasis on interaction between personality and situation (Hodson & Sorrentino, 1999), and as such provides a particularly useful lens for considering engagements in learning environments that are characterized by a degree of uncertainty, such as a science classroom. A need for closure is static, so a person with a need for closure always has this need to a higher or lesser degree, whereas uncertainty orientation dynamically interacts with the aspects of the situation (Sorrentino et al., 2008). That is, UO and CO individuals engage in systematic information processing only when there is uncertainty to be resolved, or when there is certainty to be maintained, respectively (Sorrentino et al., 2008).

Researchers in science education have emphasized scientific uncertainty as an integral and unavoidable characteristic of scientific enterprise. They aimed to illuminate learners’ understanding of scientific uncertainty, approaching it from the macro level in research on NOS and from the micro level through the studies of scientific uncertainty that emerges in scientific inquiry (e.g., Kirch, 2010; Kirch & Siry, 2012). Hence, students engaged in collaborative learning and inquiry in science education can encounter various types of uncertainty that can be difficult for groups to manage. In order to overcome such challenging situations, groups have to rely on effortful monitoring and control of their cognition, metacognition, behavior, motivation and emotions in order to achieve their learning goals.

**Regulation of Learning**

Although research on collaborative learning has been around for decades, systematic research focused on the collective regulation of learning in collaborative groups dates back only about 10 to 15 years. SSRL researchers strive to understand how groups monitor and control various aspects of their collaborative interactions and how this social regulation shapes groups’ learning experiences (Panadero & Järvelä, 2015). SSRL refers to the dynamic processes of
groups’ joint “negotiated, iterative fine-tuning of cognitive, behavioral, motivational, and emotional conditions/states as needed” (Hadwin et al., 2018, p. 83). Although the SSRL field of scholarship differs in researchers’ focus from the field of research on collaborative learning, where researchers study joint construction of knowledge and engagement (e.g., Barron, 2000; Roschelle, 1992; Sinha et al., 2015), the two fields are related and complementary. Hadwin et al. (2018) emphasized that both productive collaborative learning and socially shared regulation of learning develop over time, through group’s multiple collaborative sessions (e.g., Rogat & Linnenbrink-Garcia, 2011; Ucan, 2017). Hadwin and colleagues argued that SSRL research can contribute to resolution of some well-known problems in collaborative learning (e.g., group members’ off-task engagement, group’s affective problems), thus enriching the theory and practice of collaborative learning. Successful collaboration necessitates that group members engage in self-regulation, in mutual support of each other’s regulation of learning and in collective regulation of the group’s learning (Järvelä et al., 2013).

SSRL research has its roots in research on SRL (Hadwin et al., 2018), which developed from applications of Bandura’s (1986) socio-cognitive theory to studies of learning (Greene, 2018). SRL researchers have focused on regulative processes at the level of an individual student (e.g., Azevedo, Moos, Greene, Winters, & Cromley, 2008; Cleary & Platten, 2013; Efklides & Petkaki, 2005; Zepeda, Richey, Ronevich, & Nokes-Malach, 2015), whereas SSRL researchers have studied regulation of learning that takes place within the groups of learners (e.g., Borge & White, 2016; Iiskala et al., 2015; Malmberg et al., 2017; Panadero, Kirschner, Järvelä, Malmberg, & Järvenoja, 2015). Thus, SSRL research shares key constructs and conceptualizations with SRL research. I discuss them in the following sections.
Self-regulated learning. As mentioned in Chapter I, SRL researchers use the term self-regulated learning to refer to the “ways that learners systemically activate and sustain their cognitions, motivations, behaviors, and affects toward the attainment of their goals” (Schunk & Greene, 2018, p. 1). Winne (1995) referred to SRL as “a pivotal construct” (p. 173) in discussions about learning. Whereas there are many different models of SRL (e.g., Boekaerts, 1995; Efklides, 2011; Pintrich, 2000; Winne & Hadwin, 1998; Zimmerman, 2013), there are significant commonalities between them with respect to targets, phases, and processes of SRL (Greene, 2018).

Targets. SRL targets include any aspect of learning that a learner can think about and consciously control (Greene, 2018). Models of SRL address six categories of targets: cognition, metacognition, motivation, behaviors, emotions, and the environment (Pintrich, 2000, Efklides 2011, Zimmerman 2013). According to Greene (2018), regulation of cognition refers to the regulation of thinking centered on the learning task, comprising task definition, goals, plans, learning strategies, and self-judgements that students make about themselves after completing the learning task. Contemporary definitions of metacognition refer to it as “thinking about thinking” (Greene, 2018, p. 26). In Greene’s combined model of SRL, metacognitive knowledge and metacognitive experiences are the two components of metacognition that are considered metacognitive targets of SRL. Metacognitive skills (i.e., planning, monitoring, controlling, and evaluating the work) are included and studied as processes in the SRL literature (e.g., Zepeda et al., 2015).

In addition to metacognition, SRL researchers have long emphasized the importance of motivation in self-regulated learning (Boekaerts, 1995; Efklides, 2011; Pintrich, 2000). Referred to as metamotivation, this target of SRL includes knowledge of various types of motivation and
motivation strategies, as well as knowledge about one’s own motivational tendencies in a given context and domain (Greene, 2018). Successful learners also actively manage a wide variety of behaviors that may arise in a response to the learning task, ranging from procrastination, more or less effective time management, to delayed gratification (Pintrich, 2000; Zimmerman, 2013), as well as emotions (Efklides, 2011; Eisenberg, Valiente, & Eggum, 2010; Sinatra & Taasoobshirazi, 2018), which play a critical role in human thinking and learning (Halpern, 2014; Immordino-Yang, 2016; Immordino-Yang & Damasio, 2007). Lastly, learners engage in regulation of the external environment to create conditions conducive to learning (Zimmerman, 2013).

**Phases.** SRL researchers agree that SRL proceeds through three distinct phases, i.e., before, during, and after learning (Greene, 2018; Zimmerman, 2013). In the before learning phase, learners activate their motivation for the learning task, define the task, and engage in planning and goal setting (Zimmerman, 2013). During learning, a number of tasks may be proceeding well, in an automated manner, with no need for regulation. However, in a situation where the task is complex or the learner deems progress to be unsatisfactory an effective learner will use a variety of learning strategies and engage in active monitoring, control, and adaptation of cognition, metacognition, behavior, affect, and environment (Efklides, 2011; Pintrich, 2000). Greene (2018) noted that during learning, motivation, which played a critical role in the before learning phase, is replaced by volition – the learner’s capacity to persevere and stay engaged in the task even when experiencing difficulties. After learning, proficient self-regulated learners engage in self-evaluation of the processes that took place in the previous phases and the products that were produced as their outputs (Pintrich, 2000). Learners who are not so proficient at the self-regulation of learning, may skip the after learning phase all together or depend on external
evaluations to determine their success or failure (e.g., Järvelä, Järvenoja, Malmberg, Isohätälä, & Sobocinski, 2016; Spruce & Bol, 2015). Spending time to reflect on the learning experience and evaluations is important, because based on these evaluations learners will form either positive or negative attributions for the learning outcomes or experience positive or negative emotions related to their learning experience (Efklides, 2011). In turn, these interpretations will influence how learners approach the subsequent learning situations (Winne & Hadwin, 1998). Phases are recursive and loosely ordered as the learners may skip them, or move freely between them depending on the detected need to re-engage with a previous phase and address the task more effectively (Greene, 2018; Winne & Hadwin, 1998; Zimmerman, 2013).

**Processes.** When a learner is making satisfactory progress toward a learning goal by relying on already mastered, effective, and automated actions, there is no need to engage in effortful regulative processes (Greene, 2018). However, when learners detect dissonance, they will engage in intentional regulatory processes of monitoring and control (Greene, 2018; Winne & Hadwin, 1998). In each of the learning phases, learners engage in monitoring, e.g., they assess how well the product of the current learning phase corresponds to the standard set by the learner (Winne & Hadwin, 1998). If the fit between the product and standard is not to the learner’s satisfaction, the learner may decide to abandon the task, continue the current approach or change it (Greene, 2018). Control means implementing changes; in other words, adapting either the targets of SRL, the standards set for the products, the learning strategy, or the product of one of the previous phases of learning (Winne & Hadwin, 1998). For example, a student may realize that the library became too noisy and decide to look for a quieter location or that the initial plan to study for four hours straight was unrealistic and decide to take a break.
Three modes of regulation in collaborative learning. As described in Chapter I, during collaboration, regulation of learning unfolds through three primary regulatory modes: SRL, coRL, and SSRL. SRL refers to the deliberate regulative processes of planning, monitoring, evaluation, and adaptation that an individual learner undertakes during the group task, whereas SSRL refers to the group’s jointly and deliberately initiated and enacted regulative processes (Hadwin et al., 2018). Hadwin et al. (2018) defined coRL as “the dynamic metacognitive processes through which self-regulation and shared regulation of cognition, behavior, motivation, and emotions are transitionally and flexibly supported and thwarted” (p. 83).

Through this definition of coRL, Hadwin and colleagues emphasized the importance of coRL in shifting the regulatory ownership toward the group or toward an individual learner as needed to overcome challenges. Additionally, the authors clarified that coRL implies distributed regulatory expertise across people, and not just one more knowledgeable other (Hadwin et al., 2018). CoRL can be initiated by the learner who needs the support, by others who may realize that a learner needs a specific type of support (e.g., a reminder to take notes while reading text), or technology (Hadwin et al., 2018). Likewise, the necessary and temporary regulative support for a learner can come from one person, multiple members of the group, technology, or even a whole group (Miller & Hadwin, 2015). The co-regulative support can stimulate regulation in one person or multiple members of the group at the same time. Hadwin et al. pointed out that in the case of group regulative engagement the boundary between coRL and SSRL becomes blurred. However, coRL occurs when strategic monitoring, control, evaluation, and adaptation of one or more multiple regulation targets is appropriated by the individual learner or by a group (Hadwin et al., 2018). Hence, productive and opportune co-regulation is critical for both self-regulation and socially shared regulation. SRL and coRL are complementary to and necessary for shifting
toward SSRL, and episodes of SRL and coRL are often embedded in the episodes of SSRL (e.g., Dragnic-Cindric, Lobczowski, Greene, & Murphy, 2018; Grau & Whitebread, 2012). Hence, there is no mode of social regulation of learning that is the best; rather, what matters for successful social regulation of learning is that the group purposefully and strategically shifts toward the regulative mode that is most effective for managing the encountered challenge.

In addition to the three primary modes of regulation that characterize collaborative learning, it is important to mention that researchers have also identified directive other-regulation (e.g., Rogat & Adams-Wiggins, 2014). Directive other-regulation is similar to coRL in its focus on regulation of others in the group. However, the critical difference between directive other regulation and coRL is in the intent of the directive other-regulators to ensure their own control over the groups’ task and centrality of their own contributions (Rogat & Adams-Wiggins, 2014). In contrast, co-regulators serve to temporarily support other the person’s regulation toward achievement of the group’s goal. Social regulation of learning has emerged as an umbrella term encompassing all forms of regulation occurring during group work (Hadwin et al., 2018).

**Empirical literature on SSRL.** Empirical SSRL studies thus far involved participants across different age groups, ranging from higher education (e.g., Bakhtiar et al., 2017; Khosa & Volet, 2014; De Backer, Van Keer, & Valcke, 2015; Järvelä & Järvenoja, 2011) to K-12 students (e.g., Grau & Whitebread, 2012; Iiskala et al., 2015; Rogat & Linnenbrink-Garcia, 2011; Ucan, 2017; Ucan & Webb, 2015). Researchers have examined SSRL in a variety of task types, such as collaborative inquiry tasks in science (e.g., Ucan, 2017; Ucan & Webb, 2015), joint creation or analysis of case situations (e.g., Bakhtiar et al., 2017; Järvelä et al., 2013), joint problem formulation and solving (e.g., Näykki et al., 2014), and reciprocal peer tutoring (e.g., De Backer et al., 2015). Typically, participants in the studies engaged in a series of collaborative work
sessions to complete the tasks, thus allowing for analysis of temporal development of regulative processes (e.g., De Backer et al., 2015; Grau & Whitebread, 2012; Ucan, 2017). In addition to collaborative work, in most of the studies researchers provided opportunities for whole class sessions and students’ individual work prior to or following collaborative learning (e.g., Bakhtiar et al., 2017; Rogat & Linnenbrink-Garcia, 2011). Research methods in studies of face-to-face collaborative engagements involved video and discourse analysis of groups’ interactions and interviews with participants. Researchers relied on quantitative and qualitative data analysis to describe SSRL processes.

Findings suggest that all collaborative groups encounter socio-emotional challenges but what separates successful groups from those that are not successful is whether or not they recognize such challenges and if and how they regulate through them (e.g., Bakhtiar et al., 2017; Järvenoja & Järvelä, 2013; Näykki et al., 2014; Rogat & Linnenbrink-Garcia, 2011). Group conditions at the very onset of the collaborative activity, such as the perception of group members that they are collectively responsible for regulation of learning, seem to have an impact on the regulative processes that take place during the planning of group’s work and group socio-emotional climate that subsequently develops (Bakhtiar et al., 2017; Rogat & Linnenbrink-Garcia, 2011). A group’s socio-emotional climate is the stable pattern of shared emotions, interactions, and behaviors observable over a longer period of time (Bakhtiar et al., 2017). In the face of emotional challenges, successful groups jointly regulated their emotions to prevent further conflict and restore positive climate (Järvenoja & Järvelä, 2013). Positive affect and positive group interactions (i.e., active listening and respect, fostering group cohesion, actively working to include all group members, etc.) cyclically sustained each other leading to positive group climate (Bakhtiar et al., 2017; Linnenbrink-Garcia et al., 2011; Rogat & Linnenbrink-
Garcia, 2011) and higher engagement on task (Linnenbrink-Garcia et al., 2011). Likewise, negative affect and negative group interactions (i.e., explicit discouraging of peers’ participation, disrespect, bullying, rejection, low group cohesion, etc.) were cyclically related and led to overall negative group climate and lower engagement (Linnenbrink-Garcia et al., 2011). Lower engagement and withdrawal of group members from collaborative work ultimately caused groups with negative group climate to lose out on contributions of disengaged group members (Linnenbrink-Garcia et al., 2011). Researchers also found that the presence of a dominator in a group led to negative interactions and impeded groups’ regulative processes (Rogat & Linnenbrink-Garcia, 2011). Students reported relying on SRL and SSRL modes of regulation, but not on other-regulation to overcome socio-emotional challenges (Järvenoja & Järvelä, 2009).

SSRL researchers found that group members often interpreted the same shared event in different ways, indicating that students’ personal characteristics interlace with the group’s regulative processes (Järvenoja & Järvelä, 2009; Linnenbrink-Garcia et al., 2011; Näykki et al., 2014). For example, because they interpreted the same event in different ways, different group members chose different strategies for their individual regulation of emotions, and enacted problem-, task-, and avoidance-focused strategies (Näykki et al., 2014). Näykki et al. (2014) described how a conflict episode led some members of a collaborative group to alter their learning goals and lower their task engagement, employing an avoidance-focused strategy, while others stayed engaged, focusing on the task. The group did not attempt to jointly address the socio-emotional challenge through the use of problem-focused regulation (Näykki et al., 2014). Whereas the group completed the task, group members failed to fulfill their desired individual learning goals (Näykki et al., 2014).
Whether they are working alone or in groups, self-regulated learners’ choice of regulative and learning strategies also depends on the learning context as well as on the task type and complexity (Järvelä et al., 2013; Lodewyk, Winne, & Jamieson-Noel, 2009; Malmberg, Järvelä, & Kirschner, 2014). Complex problem solving necessitates both group members’ socio-emotional and cognitive engagement (Järvelä, Järvenoja, et al., 2016; Van den Bossche, Gijselaers, Segers, & Kirschner, 2006). In collaborative inquiry in science, when students worked on ill-structured tasks (e.g., Grau & Whitebread, 2012; Iiskala et al., 2015; Ucan, 2017), an unclear path to the solution necessitated that the group members rely on each other for successful problem solving (E. G. Cohen, 1994b; Lodewyk et al., 2009). Positive socio-emotional interactions at the start of the collaborative engagement led to productive cognitive engagement (Järvelä, Järvenoja, et al., 2016; Rogat & Linnenbrink-Garcia, 2011; Ucan, 2017; Ucan & Webb, 2015) and high-level metacognitive regulation, such as identifying task requirements, planning the approach, monitoring of the group’s understanding and task progress, and evaluating the quality of the problem solving outcomes after the task is complete (De Backer et al., 2015; Iiskala et al., 2015; Rogat & Linnenbrink-Garcia, 2011). High quality regulative processes (i.e., regulation of motivation, emotions, behavior, cognition and metacognition) worked synergistically (Rogat & Linnenbrink-Garcia, 2011; Ucan & Webb, 2015) and enabled successful groups to focus on monitoring their content understanding. Such groups engaged in exploration of ideas, questioning, and providing of elaborated explanations, all leading to deeper understanding of the content (Khosa & Volet, 2014; Rogat & Linnenbrink-Garcia, 2011).

However, empirical findings from studies of individual learners suggest that task structure (i.e., well-structured vs. ill-structured task) might have different influences on students of different SRL proficiency (Malmberg et al., 2014) and academic achievement levels.
(Lodewyk et al., 2009). Students differ in how they assess the task, modify, and respond to it (Efklides, 2011; Greene et al., 2015; Lodewyk et al., 2009; Malmberg et al., 2014). For example, Malmberg et al. (2014) found that more competent self-regulated learners who provided an accurate task solution for ill-structured tasks in 5th-grade science employed fewer learning strategies and applied them in the later phases of learning, using the time early on in the studying to plan and elaborate task demands. In contrast, students who provided inaccurate solutions used more learning strategies (Malmberg et al., 2014). Malmberg and colleagues concluded that task design might have adversely impacted some of the learners and led to reactive, rather than strategic and deliberate use of the learning strategies.

Although some researchers (Iiskala et al., 2015; Panadero & Järvelä, 2015; Panadero et al., 2015) have called for paying closer attention to the collaborative group make-up with the aim of discerning how group members’ individual characteristics may be shaping group’s SSRL processes, influence of individual differences on groups’ social regulation of learning remains under-researched. SSRL scholars, however, have made strides in making differences in group members’ perceptions and judgments apparent to the others in the group by designing computer supported collaborative learning (CSCL) tools to support SSRL and enhance the conditions for productive collaboration (Järvelä et al., 2015; Miller & Hadwin, 2015; Panadero et al., 2015). Järvelä et al. (2015) elucidated three key design principles for supporting students’ SSRL: (a) elevating students’ awareness of their individual and others’ learning processes; (b) facilitating externalizing of group members’ learning processes and supporting; and (c) prompting the activation of regulatory processes and their acquisition. Whereas the collaborative learning tools support groups’ communication and construction of knowledge, SSRL CSCL tools support
groups’ regulation of cognition, behavior, motivation, and emotions and all three modes of regulation of learning, SRL, coRL, and SSRL (Miller & Hadwin, 2015).

The field is still lacking empirical studies demonstrating the effectiveness of the CSCL tools (Järvelä, Kirschner, et al., 2016). However, the emerging work (Järvelä & Hadwin, 2013; Malmberg, Järvelä, Järvenoja, & Panadero, 2015; Miller & Hadwin, 2015; Molenaar, Roda, van Boxtel, & Sleegers, 2012) is illustrative of different approaches and tools (i.e., collaborative roles, scripts, prompts, dynamic scaffolding) researchers have used to support students in the regulative processes of negotiation and alignment of task perceptions and learning goals, construction of strategies for successful collaborative work, monitoring and evaluation of progress and products, and adaptation. For example, Miller and Hadwin (2015) supported learners’ individual and social regulatory process by facilitating learners’ preparation, individual and group planning, task enactment, and individual reflection. The authors provided question prompts and sentence starters (e.g., what is our group expected to do in this task?) to the learners, providing additional directive for regulation of collaboration (Miller & Hadwin, 2015). Miller and Hadwin also supported externalization of learners’ feelings about the collaborative task and climate at the start, middle, and end points of the collaboration, hence helping the groups maintain positive climate.

Group awareness tools (e.g., Miller & Hadwin, 2015, Panadero et al, 2015), also known as mirroring and metacognitive tools (Järvelä & Hadwin, 2013), work by capturing group members’ individual perceptions about tasks, goals, monitoring, and emotions, summarizing them, and then reflecting them back to the group. Typically, group summaries are presented through visual displays, helping groups become aware of any existing gaps with the goal of
triggering conversations that lead to resolution of the discrepancies and construction of shared task understanding and joint plans (e.g., Miller & Hadwin, 2015; Panadero & Järvelä, 2015).

In the first study of the effects of an SSRL intervention, Panadero et al. (2015) expanded an existing collaborative learning environment, the Virtual Collaborative Research Institute (VCRI), with awareness, planning, and evaluation features aimed at supporting groups’ regulation during collaboration. Panadero and colleagues found no significant effects of their SSRL intervention on group performance, but the authors did demonstrate that it is possible to adapt existing tools students already use to support groups’ regulation processes. For science educators designing digital tools for collaborative inquiry this indicates that groups’ regulative processes could be scaffolded through the same tools that are facilitating other aspects of inquiry (e.g., modeling). Whereas emerging CSCL tools seem very promising for supporting learners’ SSRL, a science teacher who does not have readily available access to such technology needs find other ways to effectively support her students’ regulation of learning in face-to-face collaborative engagement.

While the SRL researchers have shown that teachers play an important role in promoting students’ SRL and performance (Azevedo et al., 2008; Neitzel & Connor, 2018; N. E. Perry, 1998) little is known about the influence teachers may have on the development of groups’ social regulation of learning. Järvelä, Järvenoja, et al. (2016) illuminated differences in SRL processes during teacher-led versus student-led collaborative tasks with more socio-emotional and cognitive interaction taking place during student-led than teacher-led task engagement. Student-led collaborative work provided more opportunities for SRL, and both types of engagement (i.e., socio-emotional and cognitive) took place in each of the phases of learning (Järvelä, Järvenoja, et al., 2016). However, the authors did not address social forms of regulation in this study.
In one of the first studies to consider impact of teachers’ presence on groups’ regulation of learning, Dragnic-Cindric et al. (2018) investigated social regulation of learning in groups of high-school physics students during collaborative argumentation sessions. In some of the groups the teacher was present at the group’s table for the whole discussion, whereas in other groups the teacher was present only intermittently, stopping by occasionally to check on groups’ progress. Dragnic-Cindric and colleagues found that groups with the teacher present engaged mostly in initiation-response-evaluation pattern of conversation and the teacher provided cognitive and metacognitive regulation (i.e., external regulation) of learning for the group. Hence, those students lost out on the opportunity to jointly develop task understanding, and had limited engagement in monitoring of their content understanding, as well as evaluation of the task completion. In contrast, in groups without teacher constantly present, students engaged in dialogue about the models of scientific phenomena under consideration. Those groups engaged in SSRL, CoRL, and SRL, targeting their cognition, metacognition, behavior, motivation and emotions, and used adaptive learning strategies (i.e., help seeking) when needed. Groups without teacher presence were also more off-task, suggesting that there are times when external regulation might be beneficial. The authors pointed out that teachers can teach, scaffold, and support students’ developing regulation of learning by allowing time and space for within group engagement and regulation of learning and by modeling some of the regulative processes for the groups rather than by taking them over (Dragnic-Cindric et al., 2018).

So far, SSRL researchers have not addressed teachers’ knowledge and perceptions of social regulation of learning or influence of teachers’ individual characteristics on ability to foster social regulation of learning in their own classrooms. SRL researchers found that teachers’ own perceptions and knowledge about SRL influence the way they support their students’ SRL
In science classrooms that emphasize collaborative inquiry (Driver et al., 2000), teachers are likely to also influence their students’ social forms of regulation. Hence, science teachers’ preparedness to foster collaborative and dialogic practices in small groups (Singer, Marx, & Krajcik, 2000) should include effective support of group regulative processes that take place during collaboration. SRL researchers have also emphasized the dual role of the teacher as a self-regulated learner and as a teacher of self-regulated learners and implemented teacher training programs to build teachers’ SRL and add it to their pedagogical acumen (Kramarski, 2018; Kramarski & Kohen, 2017). Similarly, developing an understanding of teachers’ social regulation of learning during participation in collaborative inquiry will help illuminate the role they will play in nurturing social regulation of learning of their own students, as well as the resources they bring to the collaborative group and those they are yet to acquire.

**SSRL framework for the present study.** Whereas SRL researchers posited many models of SRL (e.g., Boekaerts, 1996; Pintrich, 2000; Winne & Hadwin, 1998; Zimmerman, 1989), to my knowledge, SSRL researchers have not conceptualized any models that would help describe and explain processes of social regulation of learning. Well conceptualized models of regulative processes, which stem from prior empirical findings and theoretical discussions in the field, provide not only explanatory but also generative power that informs and guides future research and practice (Greene & Azevedo, 2007). Efklides (2011) pointed out that emphasis a model places on the self or on the task necessarily shapes investigators’ conceptualizations of regulative processes that take place during learning. Hence, the absence of SSRL models that could explicate relationships between the aspects of the task, the individual characteristics of the learners in a group, and the processes that connect them is problematic.
In a recent book chapter, Hadwin et al. (2018) recognized and attempted to remedy this problem by suggesting that the COPES model (Winne & Hadwin, 1998) of SRL could be adapted for studying of regulation at the group level. The key feature of the COPES model, its focus on cognitive processes of SRL and cognitive architecture that facilitates them, is also replicated in the adapted COPES model for SSRL. I review the COPES SRL model and its adaptation for SSRL in detail in the sections that follow. Briefly, in addition to not making explicit the role of affect and emotions in group learning, the COPES SSRL model provides little direct information about how group members’ personal characteristics might be interacting with the task and the group. In following two sections, I review SRL models created by Efklides (2011) and by Winne and Hadwin (1998) that combined can help bridge the identified gap. Next, drawing upon both reviewed SRL models, I posit a framework for my study of social regulation of learning triggered by situational uncertainty.

**The metacognitive and affective model of self-regulated learning (the MASRL model).** Models of SRL differ in the emphasis placed on different aspects of the SRL and different levels at which SRL processes are described, such as person level or task level (Efklides, 2011; Greene, 2018). Person level is also referred to as macro level, because it includes SRL functions that span different domains, tasks, and situations (Efklides, 2011). Task level is also referred to as micro level because it focuses on SRL functioning as related to a specific task. Whereas many researchers focused on the person level in their SRL models and conceptualized SRL processes as driven by the active learner top-down (e.g., Pintrich, 2000; Zimmerman, 2000), Winne and Hadwin (1998) in their COPES model focused on the cognitive architecture based on the aspects of the task that student needs to address during learning. For the purpose of my study, in this section I focus on the MASRL model (Figure 2.2), in which Efklides
(2011) incorporated both levels of processing, the Person level and Task x Person level that recursively and dynamically influence and shape one another. Efklides also explicitly depicted Task as a standalone component of the model, which influences both the Person and Task x Person level.

In her MASRL model, Efklides (2011) emphasized regulation of cognition, motivation and affect, and de-emphasized self-regulation of behavior and environment. Her model is unique because it brings together two areas of scholarship, research on motivation and research on metacognition that have developed independently of each other (Efklides, 2011). Efklides makes several additional key contributions with the MASRL model: clear explication of influence of stable personal traits on regulation of learning, emphasis on the role of affect for learning, elucidation of interactions between different components within and across levels, and recursive relation between Person and Person x Task levels.

Efklides (2011) accounted for individual differences within the Person level. Explication of individual differences in turn makes it clear that individual learners interact with the task at the Task x Person level in very different ways. Specifically, the Person level in MASRL model includes seven stable personal characteristics that have been formed through prior learning engagements: (a) cognition, (b) motivation, (c) self-concept, (d) affect, (e) volition, (f) metacognitive knowledge (MK), and (g) metacognitive skills (MS; Efklides, 2011). Cognition includes learners’ ability, knowledge, skills, and competencies. Efklides conceptualized motivation at the Person level as including achievement goal orientations and expectancy-value beliefs. Self-concept relates to learner’s representations of hers or his own competence for a specific domain. Affect includes attitudes and emotions related to learning. Volition includes perceptions of control, in other words, learner’s beliefs about being an active agent. Lastly, Efklides included metacognition at the Person level as MK and MS. MK comprises declarative knowledge about tasks, goals, strategies, self and others as learners, as well as epistemic cognition and implicit theories of intelligence (e.g., a belief that intelligence is malleable). MS encompasses learner’s SRL strategies, such as planning, monitoring, self-evaluation, that a learner typically uses to regulate learning. These characteristics interact with each other to determine the general nature of a person’s engagement with a specific task at hand (Efklides, 2011). The top-down SRL processes take place at the Person level before or after the actual work on the task happens at the Task x Person level. At the Person level, the learner makes decisions on whether and how to engage in the task, as well as general plans and assessments of the task, relying on explicit knowledge or implicit knowledge and automatic processes, which may be cognitive or affective (Efklides, 2011). For example, a student could broadly assess the physics
problem at hand as a problem with falling bodies (MK about the task), or start to feel uneasy just reading the problem (an implicit affective reaction).

However, the online processing of the specific task and enactment of SRL, or micro-level processing (Greene & Azevedo, 2009), according to the MASRL model, happens at the Task x Person level (Efklides, 2011). Efklides (2011) positioned the four functions that operate at this level (i.e., cognition, metacognition, affect and self-regulation of affect and effort) next to each other in the model, emphasizing close connections among them. Efklides did not include motivation as a separate component in the Task x Person level, but she emphasized that motivation emerges during task processing from metacognitive and affective experiences related to the aspects of the task (i.e., interesting topic, familiarity, novelty, etc.), and includes intrinsic motivation, and motivation triggered by emotional states such as uncertainty stemming from dissonance (e.g., new information that is in disagreement with previous knowledge). Efklides posited that effective SRL at the Task x Person level necessitates two-process model of thinking that includes conscious, slow, analytical processing and explicit knowledge as well as fast, nonconscious, automatic processing, (i.e., heuristic processing), and implicit knowledge (Kahneman, 2013). Heuristic processing underpins cognitive processing and metacognitive feelings that develop during task processing (Efklides, 2011).

Processing of the specific task at the Task x Person level unfolds through three phases: (a) task representation, (b) cognitive processing, and (c) performance (Efklides, 2011). Task representation at the Task x Person level precedes the actual cognitive processing of the task. In the task representation phase the learner refines initial task evaluation and engages in goal setting and planning taking into the account specific details of the task. Both heuristic and analytic thinking might be involved in the forming of task representation. Heuristic processing is
effortless and automatic and evokes prospective metacognitive experiences (ME) indicative of successful learning outcome, such as feelings of knowing or ease of learning, that lead to neutral or positive affect (Efklides, 2011). In contrast, the analytic thinking is triggered by some encountered dissonance (i.e., lack of knowledge required for the task). Prospective ME that occur are feelings of difficulty or lack of understanding, indicative of possible unsuccessful learning outcome, leading to a negative affective state. As a consequence of becoming aware of such ME and related affect, the learner, switches from goal-driven, top-down regulative processes to bottom-up, data driven monitoring and control of task processing and affect (Efklides, 2011).

In the cognitive processing phase, the learner works on the actual task (Efklides, 2011). According to Efklides (2011), automatic processing during the task representation phase leads to effortless, automatic processing of the task in the second phase, requiring no regulation of learning. However, task representations formed through effortful, analytical processing have a greater potential to lead to active regulation of learning in this phase (i.e., monitoring and control due to detected cognitive interruptions). Efklides pointed out that interruptions in cognitive processing of the task, may occur for various reasons, such as absence or insufficiency of the preexisting cognitive schemas needed for task completion, dissonance in possible task solutions, and constant distractions. Learners become aware of the cognitive interruptions through ME such as feelings of difficulty, and based on the monitoring of ME, engage in deliberate control of learning and determine what MS to use. Learners may also engage in active regulation of affect and effort if they deem them to be subpar for effective and successful task solving (Efklides, 2011).
In the last phase at the Task x Person level in the MASRL model, the performance phase, explicit evaluation of the performance (i.e., output) takes place. If the learner’s ME related to the evaluation of the outcomes of the cognitive processing phase (e.g., feeling of satisfaction, feeling of confidence) inform him or her that the goal of the task processing has been achieved, positive affect follows, and the learner subsequently engages in self-observation and reflection on the learning experience (Efklides, 2011). Negative feedback from the evaluation of the work products and monitoring of the outcome and affect might indicate that the learner needs to return to one of the previous two phases, thus re-engaging in the task representation or cognitive processing (Efklides, 2011).

Empirical support for the MASRL model and existence of complex interactions between components of the models within and across two levels has been building up over the past decade (e.g., Dermitzaki, Leondari, & Goudas, 2009; Efklides & Petkaki, 2005; Harder & Abuhamdieh, 2015; Jiang & Kleitman, 2015; Papantoniou et al., 2012; Tornare, Czajkowski, & Pons, 2015). In their studies, MASRL researchers have relied on quantitative methods for the analysis of self-questionnaires or quantified observational data (e.g., Dermitzaki et al., 2009). As previously mentioned, one important contribution of the MASRL model is its emphasis on influence of personal characteristics and affect for students’ SRL (Efklides, 2011).

One of the key personal characteristics is self-concept, which captures a learner’s sense of competence in a particular domain (Efklides & Tsiora, 2002). Efklides and Tsiora (2002) have demonstrated a recursive relationship between self-concept and ME, such as feelings of difficulty, estimate of effort, and estimate of solution correctness. Student’s existing self-concept and previous achievement level in mathematics influenced their MEs for dealing with the task at hand. Students’ monitoring during engagement in the task formed new MEs and influenced task-
specific self-concept, which in turn, updated the learners’ self-concept in the domain (Efklides & Tsiora, 2002). Self-concept was also related to students’ motivation as reflected in students’ involvement and initiative taking during task solving and persistence on task in the face of difficulties (Dermitzaki et al., 2009; Efklides & Tsiora, 2002).

Affect also impacts ME (Efklides & Petkaki, 2005) and students’ strategy use during learning (Papantoniou et al., 2012). Efklides and Petkaki (2005) studied effects of mood, math ability and self-concept on ME and math performance. Efklides and Petkaki found that effects of induced positive or negative moods prior to solving a math task were more apparent in students’ retrospective ME (i.e., ME after task engagement) than in prospective ME (i.e., ME prior to the engagement in the task). The authors posited that ME experienced during the task influenced a resultant affect. For example, ME such as ease of task processing, increased positive affect, and interruptions and discrepancies contributed to the increase in negative affect. Math ability and math self-concept predicted prospective MEs. Math performance was predicted only by math ability and the authors found no impact of mood on math performance. However, mood did have effect on ME and emotions such as feeling of difficulty, which are critical for engagement in regulation of learning (Efklides & Petkaki, 2005).

In addition to the induced affect, researchers also studied effect of discrete emotions, such as contentment, pride, joy, worry, shame and hopelessness (Tornare et al., 2015), and trait affect (Papantoniou et al., 2012) on students’ SRL. Tornare et al. (2015) found that ME (i.e., feeling of difficulty or feeling of success) were better predictors of discrete emotions students experienced after a task than self-concept. Feeling of difficulty during problem solving contributed to the elicitation of hopelessness, and reduced feelings of joy and contentment, whereas feeling of success increased students’ feelings of pride and joy and decreased feelings of
shame. Emotions related to the objective task performance were mediated by ME, except in the case of hopelessness (Tornare et al., 2015). Researchers found that students’ positive trait affect was related to the higher use of SRL strategies (e.g., help-seeking, rehearsal, elaboration, management of study environment and time), whereas negative trait was not related to the SRL strategy use (Papantoniou et al., 2012). Negative affect was related to the cognitive interference and through it to the students’ course performance, as measured by the course grade (Papantoniou et al., 2012).

With respect to my study, it is of particular interest to consider how a personal characteristic of a group member, such as person’s uncertainty orientation, might influence the student’s and group’s regulation of learning during collaborative inquiry. At Task x Person level, I expect that students’ uncertainty orientations might cause different affective and, in turn, regulative responses as students engage in tasks that cause them to experience cognitive fluency or disfluency (i.e., ease of cognitive processing of the given material), interruptions, discrepancies, or become aware of gaps in knowledge (Efklides, 2017; Efklides, Schwartz, & Brown, 2018). For example, for students who are uncertainty-oriented, dissonance experienced during collaborative inquiry in science, and the related feeling of difficulty, might arouse curiosity and lead to engagement in deeper exploration to resolve uncertainty (i.e., adaptive response). For certainty-oriented students, who orient away from uncertainty, and react negatively to it, responses to the feeling of difficulty might be different, such as attempting to come to a quick conclusion based on limited information, thus disengaging from further exploration.

COPES model. Winne and Hadwin (1998) posited a model of self-regulated learning with four “recursive, weakly sequenced” (p. 127) phases: task definition, goal setting and
planning, enactment, and adaptation (Figure 2.3). All four phases have a cognitive architecture based on conditions, operations, products, evaluations, and standards (COPES; Winne & Hadwin, 1998), which are interrelated facets common to all learning tasks. Monitoring and control are present in each of the four phases of learning.

In the task definition phase, the learner forms an initial impression about the learning task, as well as the factors that might impact its completion (i.e., prior knowledge of the subject matter, time available for the task). In the second phase, the goal setting and planning phase, the learner uses the initial impressions about the task to set personal goals and develop plans for addressing it. In the third phase, the task enactment phase, the learner carries out the plan created in the second phase. Finally, in the fourth phase, the adaptation phase, learner makes changes to cognitive structures that may impact the immediate task at hand, future learning tasks, or both; in other words, the conditions for the next learning engagement are adapted (Winne & Hadwin, 1998).

The five facets of the learning task (i.e., COPES) delimit cognitive architecture within which the learners enact SRL and advances through the phases of learning (Winne, 2018; Winne & Hadwin, 1998). Winne and Hadwin (1998) conceptualize *conditions* as characteristics unique to the person (i.e., cognitive conditions: beliefs, dispositions, styles, motivational factors, knowledge of domain, task, and study tactics and strategies) and environment (i.e., task conditions: social context, instructional cues, time and other resources) that foster or constrain engagement in the specific learning task. Thus, cognitive conditions are the equivalent of the Person level in the MASRL model. It is also important to point out that although motivation and affect are not prominently featured in the COPES model, they are included as cognitive
conditions. Conditions influence standards that the learner sets for the task as well as operations the learner carries out. *Operations* can be either single basic cognitive processes or multiple cognitive processes, coordinated into learning tactics and strategies, which transform conditions and create products in each stage of learning. Winne (2018) described a set of five basic cognitive operations as searching, monitoring, assembling, rehearsing, and translating (i.e., SMART operations). *Products* can be internal, cognitive outcomes, such as new knowledge, or external, that can be observed by others, such as a student’s notes during task. Products are then evaluated against previously established standards. *Standards* are goals the learner adopts for the task, which may or may not align with the teacher’s goals for the learning activity. They are the criteria against which the learner monitors progress on the task. Monitoring generates cognitive evaluations. If a result of such an evaluation is the detection of a discrepancy between a product of a learning phase and a standard, the learner might engage in control. Control means alteration of cognitive conditions, standards, or reengagement in the learning operations to improve the product. This level of monitoring, targeting products of learning phase (e.g., plan for engagement in inquiry created in second phase), is object-level monitoring. However, Winne and Hadwin (1998) pointed out that a learner may also monitor meta-level attributes that offer valuable information about the studying process and progress, such as time spent on the task and ease of learning judgements. This is metacognitive monitoring. Both object- and meta-level information combine into a comprehensive evaluation that is feedback for the learner. If, as a result of metacognitive monitoring, discrepancies are found, the learner enacts metacognitive control in form of “toggling and editing” (Winne & Hadwin, 1998, p. 129). Whereas toggling refers to quick and minor changes, such as switching studying tactics on and off, editing refers to more substantial changes to studying tactics and the constituent operations (Winne & Hadwin, 1998).
Processes of monitoring and control are present in each phase of learning and enable the learner to go back to the previous phases or enact quick, in the moment adjustments in the current phase.

Winne and Hadwin (1998) modeled SRL processes that take place when a learner is studying alone. However, collaborative learning is more complex than individual learning. During collaboration, in addition to the individual learner’s personal conditions and the task conditions, which Winne and Hadwin identified in the COPES model of an individual learner’s SRL, there are also group conditions (Miller, 2015 as cited in Hadwin et al., 2018). Group conditions include a learner’s beliefs about other members of the group (i.e., their knowledge, abilities, strengths, and weaknesses), as well as the beliefs about the group as a collective entity (i.e., group norms, climate, disciplinary knowledge, and effectiveness; Hadwin et al., 2018). Hadwin et al. (2018) suggested that the Winne and Hadwin’s (1998) COPES model might be especially well suited for studies of social regulation of learning because it is possible to capture the dynamic relationships between the individual, social, and environmental conditions that shape regulation of learning. In the proposed adaptation of the COPES model for SSRL studies, Hadwin and colleagues emphasized that the products at the person level are in reciprocal relationship with the conditions at the group level, thus the products at the individual level become conditions at the group level and products from the group level update conditions at the person level.

**Proposed Framework**

In this study, I aim to explore and describe how groups of preservice teachers navigate through uncertainty during collaborative inquiry in science. Learners engaged in collaborative inquiry in science also encounter scientific uncertainty, which is an integral part of science, hence collaborative groups are likely to encounter multiple challenges they will need to
overcome. Like Huber (2003), I operationalize situational uncertainty by introducing tasks with different levels of structure.

Sorrentino and Roney (2000) pointed out that person’s uncertainty orientation is a relatively stable personal characteristic that in situations of uncertainty leads people to engage with the new information and novel situations in very different ways. UO persons orient toward uncertainty and attempt to resolve it through active engagement with it, whereas CO persons avoid or ignore uncertainty in order to preserve current clarity. Hence, a framework is necessary that captures individual differences in uncertainty orientations as one of the learner’s personal characteristics (i.e., Person level, Efklides 2011 or individual conditions, Winne & Hadwin, 1998). Such a framework should also explicate the influence of tasks with different levels of situational uncertainty, on the individuals (i.e., Person level), the way they interact with the task (i.e., Person x Task level, Efklides 2011), but also on the group as a whole (i.e., Group level), and how the group interacts with the task (i.e., Group X Task level). I draw on both the MASRL model (Efklides, 2011) and the COPES model (Winne & Hadwin, 1998) and suggest that one possible way to model group regulation of learning is the framework depicted in Figure 2.4.

In this framework, learners enter into a collaborative task with their individual characteristics, such as uncertainty orientations, as well as their unique science knowledge, affect, metacognitive knowledge and metacognitive strategies (i.e., learners’ internal condition). In a collaborative group, individual learners contribute to the creation of a group’s unique internal conditions that distinguish it from all other groups (i.e., group’s conditions). Individuals’ and group’s regulation of learning will also be shaped by the context in which the collaborative inquiry takes place (i.e., external conditions).
Figure 2.4. Uncertainty orientations and social regulation of learning framework.

A given task, and the situational uncertainty it induces, influences each group member at their Person level as well as their processing of the task and individual SRL, which takes place at the Task x Person level. Affect at Task x Person level, specifically intrapersonal uncertainty experienced by each individual and their responses to it, shapes and is shaped by group task processing at the Task x Group level. The task also directly influences the group and group’s social regulation of learning which unfolds at the Task x Group level. In turn, products of a group’s social regulation of learning at Task x Group level, update group’s conditions as well as individual conditions of group members.

In my study, I am interested in how individual characteristics, specifically, preservice science teachers’ uncertainty orientations, combine with task characteristics during participation in collaborative inquiry in science and trigger a need for a group’s joint regulation of learning. I believe that that the proposed framework will enable me to analyze and think about social regulation of learning that unfolds. Describing how groups of preservice teachers regulate their
learning when they encounter scientific uncertainty during collaborative inquiry in science contributes to the knowledge on domain-specific aspects of social regulation of learning. It also contributes to the knowledge about preservice teachers as collaborative learners facing scientific as well as various levels of situational uncertainty. This study has the potential to contribute to the long term goal of understanding of how to help learners jointly, strategically, and purposefully manage the challenges that arise in collaborative inquiry.
CHAPTER 3: METHODS

With this multimethod, exploratory study, I aimed to contribute to the knowledge base on social regulation of learning by examining what occurs when groups of preservice elementary school teachers as science learners in a science methods class encounter and have to grapple with uncertainty in a series of collaborative inquiry tasks. In order to explore interactions among social regulation of learning, uncertainty, and collaborative tasks, I proposed the following research questions:

1. How do collaborative groups of elementary preservice elementary school teachers socially regulate their learning when they encounter tasks with scientific uncertainty?

2. How does preservice elementary school teachers’ enactment of social regulation of learning vary with respect to differences in the degree of situational uncertainty encountered during collaborative inquiry tasks?

3. How does regulation of learning during collaborative inquiry differ for people of different uncertainty orientations?

Study Participants and Context

Study participants. I conducted this study at a university in the southeastern United States, in one section of a science methods class for elementary preservice teachers, during the 15-week-long Fall 2019 semester. Out of 23 students enrolled in the course, 20 agreed to participate in the study. However, two students were not present during the administration of the uncertainty orientation measure, which I used as a criterion to assign participants into
collaborative groups, so I carried out this study with the 18 participants who completed the necessary measure. The majority of participants were White (83%) and female (94%), with no prior teaching experience (67%). Mean age of the participants was 23.7 years of age.

Table 3.1

Participants Self-reported Demographic Information

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Participants (N_{full\ class} = 18)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Race</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>1</td>
<td>5.6</td>
</tr>
<tr>
<td>Bi-racial</td>
<td>1</td>
<td>5.6</td>
</tr>
<tr>
<td>Hispanic</td>
<td>1</td>
<td>5.6</td>
</tr>
<tr>
<td>White</td>
<td>15</td>
<td>83.3</td>
</tr>
<tr>
<td>Gender</td>
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<td></td>
</tr>
<tr>
<td>Female</td>
<td>17</td>
<td>94.4</td>
</tr>
<tr>
<td>Male</td>
<td>1</td>
<td>5.6</td>
</tr>
<tr>
<td>Years of prior teaching experience</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2 years</td>
<td>1</td>
<td>5.6</td>
</tr>
<tr>
<td>Less than 1 year</td>
<td>5</td>
<td>27.7</td>
</tr>
<tr>
<td>No experience</td>
<td>12</td>
<td>66.7</td>
</tr>
</tbody>
</table>

*Note.* Percentages might not add up to 100 due to rounding.

The course instructor for the section of the science methods class in which I conducted my study was an experienced science teacher educator with more than ten years of teaching experience. A graduate teaching assistant was present during the fifth task (i.e., Escape Room task) and helped the course instructor with the task set-up and classroom management on that day.

**Course structure.** Preservice teachers spent the first three weeks of the semester in field placement in local public elementary schools. The 12-week classroom component of the methods
courses followed the field placement. During the classroom component, preservice teachers continued to spend two days per week in their field placement schools.

The classroom component of the science methods course included a range of inquiry activities, from structured to open, but the course instructor emphasized guided collaborative inquiry (Herron, 1971; J. Kang & Keinonen, 2018; Sadeh & Zion, 2009). Prior to any collaborative work in the class, the course instructor provided students with collaborative norms to foster students’ comfort with group discourse and argumentation. The course curriculum included discussions that addressed the tentative nature of science, but it did not include explicit instruction or discussions about personal or scientific uncertainty that necessarily occurs through scientific practices and inquiry. Preservice science teachers in this course experienced collaborative inquiry both as students participating in an inquiry-based methods course and as novice science teachers through field placement in local elementary schools.

Students in this class typically worked in five or six small collaborative groups of 3-5 students each. Traditionally, the course instructor had formed the groups based on the participants’ field placement grade level. Groups would remain stable through the semester and were seated together during each class session, so the group members had ample time to get to know each other. For this study, I formed the collaborative groups based on participants’ uncertainty orientations to ensure maximum variability as was feasible given other factors in the course. I used the participants’ field placement grade level as the secondary criterion for group placement, with the goal to keep together students who were teaching similar elementary grade levels (e.g., K-2 teachers were grouped together). Using this approach, in consultation and agreement with the course instructor, I formed a total of six collaborative groups. Five groups
had four students in them, and one group had three students. Of the six groups, two groups included non-participants or participants who did not complete the uncertainty measure.

I purposefully selected groups for video recording in a two-step process (Rogat & Linnenbrink-Garcia, 2011). As a first step, I chose the four groups in which all members consented to participate in my study. As a second step, I selected three small groups with four students in each group (i.e., \( N = 12 \)) for video and audio recording and observation ensuring maximum within-group and/or across group variability. I chose one group with all uncertainty-oriented (UO) individuals, one group with a majority of certainty-oriented (CO) individuals (i.e., three CO individuals and one moderate uncertainty orientation individual) and one group with participants of mixed uncertainty orientations (i.e., two participants of moderate uncertainty orientation, one UO individual, and one CO individual). Recording each of the three small collaborative groups through one baseline, non-inquiry collaborative task and a series of five collaborative tasks resulted in a total of 18 video-recorded, collaborative sessions.

During the collaborative sessions, the course instructor typically walked around the classroom and supported students by answering their questions or by posing appropriate questions and prompts that led to deeper thinking about investigations and engagement with the task at hand. However, the instructor did not provide task solutions to the groups and did not tell them what they were supposed to find in their investigations. In this science methods course, preservice teachers also developed an NGSS-based science unit, critically evaluated instructor-selected, commercially available curricular materials, and wrote eight reflective blog posts on the class Edmodo website. Preservice teachers’ reflective blog posts afforded an opportunity for them to reflect upon their own views of science, their early science learning experiences, and their current learning and teaching engagements in the science methods class.
Data Collection Procedures

I visited the classroom during the first classroom session to recruit participants face-to-face, using the recruitment script approved by the university’s Institutional Review Board (IRB). I did not disclose the exact purpose of the study to the participants. Instead, I informed them that the purpose of the study was to learn about the ways that preservice teachers collaborate in scientific inquiry. Thus, I did not mention terms such as regulation of learning or uncertainty. Prior to participating in the study, all participants reviewed and signed a copy of an IRB Adult Consent Form. Participants did not receive any monetary compensation for their participation and all of the activities required for the study were incorporated into the course curriculum. All signed consent forms were kept in a locked cabinet in a locked room and were accessible only by the people authorized by the IRB. No data collection occurred on the day of recruitment for the study.

The following week, during the second class session, I group-administered general demographic questionnaires and the uncertainty orientation measures to all participants, meaning that all participants completed them in class at the same time. Completion of the demographic questionnaire and both measures of uncertainty took approximately 30 minutes. As previously described, upon completing the analysis of the uncertainty orientation measures, I assigned participants to the collaborative groups and then selected groups for video recording.

Next, I video recorded groups during one approximately 10-minute long, non-inquiry collaborative work session to establish a baseline of initial group dynamics and provide a comparison point. Then, over the course of the semester, participants engaged in a series of five collaborative inquiry tasks with varying levels of uncertainty operationalized as level of task structure. Prior to each task, I assessed participants’ prospective view of task uncertainty by
asking an open-ended, non-leading question that did not mention uncertainty: “How confident are you that you know how to complete this collaborative task and why?” In Table 3.2, drawing on Herron (1971), I presented definitions of different levels of inquiry. Then, in Table 3.3, I characterized the collaborative inquiry tasks based on three dimensions: level of inquiry (Herron, 1971; Table 3.2), level of uncertainty (i.e., level of structure), and type of the scientific uncertainty characteristic for the task (Table 3.3).

Table 3.2

<table>
<thead>
<tr>
<th>Level of inquiry</th>
<th>Type of inquiry</th>
<th>Description</th>
<th>What is provided?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Question</td>
</tr>
<tr>
<td>0</td>
<td>Confirmation</td>
<td>Learners work to confirm the scientific principle through a teacher-prescribed activity. Results are known in advance.</td>
<td>X</td>
</tr>
<tr>
<td>1</td>
<td>Structured</td>
<td>Learners investigate teacher-provided question through a prescribed set of procedures. Results/outcomes are not known in advance.</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>Guided</td>
<td>Learners investigate instructor-provided question using student designed investigative procedures. Results/outcomes are not known in advance.</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>Open</td>
<td>Learners pose and investigate a topic related question using learner designed investigative procedures. Results/outcomes are not known in advance.</td>
<td>-</td>
</tr>
</tbody>
</table>


Herron (1971) posited four levels of inquiry based on the learners’ level of agency in the inquiry. Level 0, confirmation or verification inquiry, in which students engage in simple confirmation of a scientific principle by following a series of prescribed steps to obtain results known in advance, is characterized as the lowest level of learner agency. In Level 1, structured inquiry, learners investigate a question provided by the teacher through a prescribed procedure.
Level 2, guided inquiry, is characterized by student-designed investigations to explore teacher-provided questions. In Level 3, open inquiry, learners exercise the most agency, posing a topic-related, student-formed question and choosing the inquiry design and procedures to investigate it (Herron, 1971). The majority of tasks in this science methods curriculum were level 2, guided inquiry tasks, because empirical findings suggest that guided inquiry is more effective for science learning than other forms of inquiry (J. Kang & Keinonen, 2018; Sadeh & Zion, 2009). Still, within guided inquiry tasks it was possible to distinguish between tasks that are more or less structured. I determined levels of task structure (i.e., high, medium, or low) through a conversation with the course instructor. We reviewed each inquiry task for this study and considered what is known and unknown in the task, availability of multiple paths to the solution, possibility of achieving a solution, and the possibility of multiple solutions or outcomes. Considering these multiple dimensions, first, we ranked all of the inquiry tasks in order of task structure, from most structured to least structured, achieving 100% agreement. Next, I moved the task with the highest level of uncertainty (i.e., building of the bioreactor) to the front of the sequence. Hence, I originally intended to engage the preservice teachers in six collaborative inquiry tasks in the following order: (a) building of the bioreactor; (b) parachute inquiry; (c) is Bounty a quicker picker-upper?; (d) Novel STEM: egg drop experiment; (e) building a straw tower; and (d) escape room. I discuss the rationale for this task order later in this section.

However, during the detailed course session planning, which took place during the summer prior to the start of the semester when the data collection occurred, the course instructor and I realized that it was not possible to fit in the third proposed task, “Is Bounty a quicker picker-upper,” into a coherent sequence with the other course content. Hence, in consultation with my advisor and the course instructor, I made the decision to omit that task and carry out my
study with five instead of six tasks (Table 3.3). I deemed this decision to have a low impact on
the goals of the study, because the fourth task, the egg drop experiment, had the same ratings as
the third task for the level of inquiry openness as well as for the level and type of scientific
uncertainty.

Table 3.3

<table>
<thead>
<tr>
<th>Task</th>
<th>Level of inquiry openness (Herron, 1971)</th>
<th>Level of uncertainty (i.e., lack of task structure)</th>
<th>Type of scientific uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Building of the bioreactor</td>
<td>3</td>
<td>High</td>
<td>Empirical, Inductive, Interpretive, Conceptual</td>
</tr>
<tr>
<td>2 Parachute inquiry</td>
<td>1</td>
<td>Low</td>
<td>Empirical, Inductive</td>
</tr>
<tr>
<td>3 Novel STEM: egg drop experiment</td>
<td>2</td>
<td>Medium</td>
<td>Empirical, Inductive, Interpretive</td>
</tr>
<tr>
<td>4 Building a straw tower</td>
<td>2</td>
<td>Medium</td>
<td>Empirical, Inductive, Interpretive, Conceptual</td>
</tr>
<tr>
<td>5 Escape room</td>
<td>3</td>
<td>High</td>
<td>Empirical, Inductive, Interpretive, Conceptual</td>
</tr>
</tbody>
</table>

Building the bioreactor involved groups designing and building a biologically active
environment within a cylindrical vessel (i.e., a two-liter clear soda bottle) to achieve ideal
composting conditions and turn the materials into compost. Based on their knowledge of the
composting process, groups chose the materials and how much of each material to include in the
bioreactor, as well as in what order to put materials into the bioreactor. Whereas my focus was
on the initial activity of building the bioreactor, during the semester, students continued to
observe and document changes in their bioreactors, and take and record measurements of their
bioreactors (i.e., temperature, height of the materials in the bioreactor). At the end of the
semester, the groups opened their bioreactors, evaluated the outcomes of their project and
reflected on how they could have done it differently. The parachute inquiry task was the most
structured in the sequence of six tasks, and involved students building parachutes from the
instructor-provided, pre-cut materials. Then, groups conducted the experiment by dropping the parachutes and measuring the speed at which they fell. For the second part of this task, students were asked to make a parachute design change that would result in a slower fall speed. The egg drop experiment involved students determining how to protect an egg from being broken during a fall from the height of approximately eight feet. Collaborative groups chose all design elements for a container in which they placed an egg. Then, they conducted a drop experiment and analyzed the outcomes. The straw tower task involved students building a tower made of straws that had to be strong enough to be able to hold a tennis ball. Groups determined the design constraints and choose all aspects of the tower design to meet the requirement of using all of the provided straws. The last task was an escape room task, where the groups used clues to solve a series of problems related to the topic of composting. Solving each problem enabled groups to unlock a container with clues for the next problem. The design of the escape room was sequential, which is common to many escape rooms, meaning that there was only one possible solution to the current puzzle and one possible path to the next puzzle. However, the probability of being misled by the cues was high and required group members to work together to solve each problem and advance toward the task completion.

As my primary data source in this study, I collected video-recordings of small-group interactions while they worked on the tasks. I positioned stationary cameras to avoid video recording any individuals who did not consent to the participation in the study. As secondary data sources, I collected responses to pre-task questions, field observation notes, artifacts produced by the groups, and participants’ individual reflective blogs.

Over the course of the semester, groups first encountered the task with a high level of uncertainty (i.e., least structure) and then engaged in a series of tasks that started with the least
uncertain task (i.e., a well-structured task) and progressed to another task with a high level of uncertainty, at the end of the sequence. I selected this particular order of inquiry tasks, where the lower level uncertainty tasks were bracketed by tasks with high level of uncertainty, to address a potential concern about maturation and content learning that can threaten internal validity in quantitative research (Gall, Gall, & Borg, 2007). Specifically, in this exploratory study, there was a potential for a confound in the form of preservice elementary school teachers’ enactment of group regulation of learning being affected by their developing science knowledge and knowledge about inquiry over time. The purpose of the science methods course was to improve preservice elementary teachers’ knowledge of science content and methods; thus, it was reasonable to expect that maturation would occur. In my multimethod study, I aimed to describe the social regulation of learning as it happened in tasks of varying levels of uncertainty. Giving groups an opportunity to address a high uncertainty, ill-structured task at the beginning provided an insight about the way groups of preservice teachers regulated through the uncertainty prior to learning science methods or content. Then, I followed groups through the series of tasks, which gradually increased in uncertainty from task low in uncertainty (i.e., high in structure) to another task that was high in uncertainty. This sequence is representative of sequences students in a science methods class typically encounter. Having two instances at which groups engaged in a high uncertainty task, before and after science methods instruction, gave me an opportunity to qualitatively describe and compare groups’ regulation at those two time points, as well as observe differences in regulation and make inferences about potential maturation effects. Another way to address the maturation threat would have been through counterbalanced or random assignment of inquiry tasks to the groups. For example, in counterbalanced assignment, one group would go through the task sequence from the least to the highest uncertainty task,
while the other would go through the reversed sequence. However, counterbalanced and random task assignments were not possible because of the methods class’s structure and the need for all collaborative groups of preservice teachers to move through the curriculum together.

Similar to other studies of social regulation of learning (e.g., Grau & Whitebread, 2012; Malmberg et al., 2017; Rogat & Linnenbrink-Garcia, 2011; Ucan, 2017), I relied on qualitative coding of video data, described in the next section, to analyze groups’ regulation of learning. To develop full descriptions of social regulation that occurred during collaborative sessions, I utilized both quantitative and qualitative analysis of the qualitative coding. In Chapter 4, I present both my quantitative findings, as well as my qualitative findings that include participants’ quotes and in-depth, thick descriptions of groups’ interaction. However, with this study, I contribute to the methodological diversity of the SSRL and science education research by also considering individual differences among the group members (i.e., the uncertainty orientations) and how those differences related to the ways the groups dealt with uncertainty.

To answer my research questions, in addition to the previously mentioned measures of uncertainty orientations, I also used secondary data sources (i.e., preservice teachers’ reflective blogs) to illuminate participants’ general dispositions toward science and uncertainty. I examined the blogs for additional information about participants’ views of science, science learning and science teaching and uncertainty. According to the initial course plan, as a part of the curriculum, throughout the semester, preservice teachers were supposed to respond to a total of nine blog prompts: (a) science autobiography; (b) science in everyday life; (c) field placement reflection; (d) what can or cannot be composted?; (e) making a bioreactor – hypothesis reflection; (f) visit to the community garden reflection; (g) escape room reflection; (h) reflection on simulations; and (i) reflection on project-based learning experience. However, the reflection on simulations was
cancelled because the simulation website was not operational at the time students were supposed to interact with it, so the students wrote eight reflective blog posts. In my investigation, I focused on the first two blogs (i.e., science autobiography and what is science?) to learn about preservice teachers’ general dispositions toward science and provide a more holistic picture of their individual ways of dealing with uncertainty in science. I also examined participants’ blog posts about bioreactor and escape room to support my findings related to those specific tasks. Additionally, I examined their last blog post on project-based learning to glean additional information about their views at the end of the semester.

**Measure of Uncertainty Orientation**

Measures of individual uncertainty orientation included: (a) the need to resolve uncertainty measure (nUncertainty) and (b) the Cherry and Byrne’s (1977) acquiescence-free scale of authoritarianism (Sorrentino, Roney, et al., 1992). The first measure, the nUncertainty, taps a person’s need to resolve the uncertainty (Hodson & Sorrentino, 1999; Sorrentino, Roney, et al., 1992). The second measure, the measure of authoritarianism, taps the approach of certainty; in other words, a person’s need to maintain clarity (Hodson & Sorrentino, 1999; Sorrentino, Roney, et al., 1992). These two measures are independent of each other, in other words, it is possible for a person to be high or low on both measures, or high on one and low on the other, and both contribute toward predicting a person’s behavior in a given situation. The resultant uncertainty orientation score is obtained by transforming scores on each measure into z-scores and subtracting the authoritarianism z-score from the nUncertainty z-score. I provide more details about uncertainty score calculations in the data analysis section below, but ultimately a high resultant score indicates that a person is UO and a low resultant score indicates that a person is CO. A person of a moderate uncertainty orientation would score either high or
low on both measures. As discussed in Chapter 2, it is not possible to predict the behavior of moderates (Sorrentino & Short, 1977), and investigators (e.g., Hodson & Sorrentino, 2003; Sorrentino & Roney, 1986; Sorrentino et al., 2013; Szeto et al., 2011; Wang et al., 2008) have typically excluded persons with moderate uncertainty orientation from further analysis.

In my study, however, I decided to use information about uncertainty orientations of all the participants. Moderates have typically not been studied in social psychology research, so it was valuable to describe what social regulation of learning looks like in groups that include them, which are likely to occur in real life classrooms. Also, it would be interesting to describe if and how preservice teachers of moderate uncertainty orientation respond to uncertainty, because their responses might be quite different than the responses of UO or CO individuals. Hence, I categorized all participants based on their uncertainty orientation designations. I administered both uncertainty measures using the Qualtrics portal.

**The nUncertainty measure.** The purpose of this measure was to discern how participants deal with uncertainty that, according to Kagan (1972), might originate from an inability to predict the future, or the incompatibility between two ideas, an idea and experience, or an idea and behavior. Sorrentino, Roney, et al. (1992) recommended administering the measure of nUncertainty under neutral testing conditions and with no other measures administered prior to it. For this measure, participants generated short stories in response to the following four one-sentence story leads:

1. Two persons are in a laboratory working on a piece of equipment.
2. A person is sitting, wondering what might happen.
3. A person is seated at a desk with a computer and a book.
4. An older person is talking to a younger person. (Szeto et al., 2011, p. 342)
During the administration of this measure, I followed the typical approach utilized by uncertainty orientation researchers and presented sentence leads one at a time, giving participants one minute to answer each of the following four groups of questions: (a) What is happening? Who is the person? or Who are the two persons?; (b) What has led up to this situation, or what has happened in the past?; (c) What is being thought? What is being wanted? By whom?; and (d) What will be done? (Szeto et al., 2011). I repeated this process for each of the four sentence leads. Participants had a total of four minutes to write each story (Sorrentino, Hanna, et al., 1992), so the total time needed to administer this measure including giving the instructions to the participants was around 20 minutes.

**The measure of authoritarianism.** The second measure was a 21-item self-report measure of authoritarianism (Figure 3.1) that addressed orientations toward certainty (Sorrentino, Roney, et al., 1992). This measure was based on Cherry and Bryne (1977) authoritarianism measure, which has 22 items. However, in their measure of authoritarianism, Sorrentino, Roney, et al. (1992) omitted from the original scale item number 8, which states “[i]t is highly unlikely that astrology will ever be able to explain anything” (p. 422). Sorrentino and colleagues found that this item violated internal consistency of the scale and did not contribute to the predictive power of the scale. Hence, the measure of authoritarianism I used as the second measure had 21 items. According to Sorrentino, Roney, et al. (1992), the test items were scored on a 6-point scale, ranging from “I agree very much” (p. 422) to “I disagree very much” (p. 422). I scored those responses on a range from +3 to -3. High scores on the authoritarianism measure were indicative of high levels of authoritarianism.

One potential limitation of the Cherry and Byrne’s (1977) scale was that some of the language (e.g., references to a person’s honor and breeding) of this more than forty-year-old
scale might feel irrelevant or archaic to 21st century learners and as such might influence their ability to comprehend the related items and provide adequate responses. Although researchers who completed uncertainty orientations studies with college students in recent years reported no such issues (see Li, Sorrentino, Norman, Hampson, & Ye, 2017; Sorrentino et al., 2008; Szeto et al., 2011), it might be beneficial nonetheless to mitigate the concern about archaic language by updating the wording of the items. However, such a change would introduce the risk of altering the psychometric properties of the scale and call into question the uncertainty orientation measurement results. Hence, changes to the wording would necessitate re-validation of the scale. Due to the limitations in time and resources available for this study, re-validation or a creation and validation of a new authoritarianism measure, which are typically a topic of political and social psychology, were beyond the scope of work for this study.
Instructions to Subjects:
PUBLIC OPINION SCALE

The following sets of items are an attempt to assess the opinions of college students about a number of important personal, academic, and social issues. The best answer to each statement is your personal opinion. We have tried to cover many different and opposing points of view; you may find yourself agreeing strongly with some of the statements, disagreeing just as strongly with others, and perhaps uncertain about others; whether you agree or disagree with any statement, you can be sure that many people feel the same way you do.

Mark your opinion about each statement on the answer sheet (following the statements) according to how much you agree or disagree with it. Please mark every one.

(P) 1. There is hardly anything lower than a person who does not feel a great love, gratitude, and respect for his parents.
(P) 2. An insult to our honor should always be punished.
(P) 3. Books and movies ought not to deal so much with the unpleasant and seamy side of life; they ought to concentrate on themes that are entertaining or uplifting.
(P) 4. What the youth needs most is strict discipline, rugged determination and the will to work and fight for family and country.
(R) 5. No sane, normal, decent person could ever think of hurting a close friend or relative.
(P) 6. Young people sometimes get rebellious ideas, but as they grow up they ought to get over them and settle down.
(R) 7. The findings of science may some day show that many of our most cherished beliefs are wrong.
(R) 8. It is highly unlikely that astrology will ever be able to explain anything.
(R) 9. People ought to pay more attention to new ideas, even if they seem to go against the American way of life.
(P) 10. If people would talk less and work more, everybody would be better off.
(P) 11. A person who has bad manners, habits, and breeding can hardly expect to get along with decent people.
(R) 12. Insults to our honor are not always important enough to bother about.
(R) 13. It's all right for people to raise questions about even the most sacred matters.
(P) 14. Obedience and respect for authority are the most important virtues children should learn.
(R) 15. There is no reason to punish any crime with the death penalty.
(R) 16. Anyone who would interpret the Bible literally just doesn't know much about geology, biology, or history.
(P) 17. In this scientific age the need for a religious belief is more important than ever.
(R) 18. When they are little, kids sometimes think about doing harm to one or both of their parents.
(R) 19. It is possible that creatures on other planets have founded a better society than ours.
(R) 20. The prisoners in our corrective institutions, regardless of the nature of their crimes, should be humanely treated.
(P) 21. The sooner people realize that we must get rid of all the traitors in the government the better off we'll be.
(R) 22. Some of the greatest atrocities in man's history have been committed in the name of religion and morality.

Scoring Key
On a six-point scale, items are scored in the following way:

<table>
<thead>
<tr>
<th>Strong support, agreement</th>
<th>Moderate support, agreement</th>
<th>Slight support, agreement</th>
<th>Slight opposition, disagreement</th>
<th>Moderate opposition, disagreement</th>
<th>Strong opposition, disagreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>(P)</td>
<td>(R)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

(Omitted items receive a score of 4.)

Figure 3.1. Authoritarianism scale. Adapted from Cherry, F., & Bryne, D. (1977).

Authoritarianism. In T. Blass (Ed.), *Personality variables in social behavior*, pp. 118-119.

Copyright by Erlbaum.
Also, I considered replacing the Cherry and Byrne measure with a more recent scale of authoritarianism. Researchers on authoritarianism most frequently rely on a Right-Wing Authoritarianism (RWA) measure (Altemeyer, 1981, 1998) or one of its versions in their studies. The limitation of this scale, and its more recent counterpart, the Left-Wing Authoritarianism scale (Van Hiel, Duriez, & Kossowska, 2006) was that they carry ideological valance and, hence, are asymmetric in their conceptualization of types of authoritarianism (see Martin, 2001 for a complete discussion).

More recently, Dunwoody and Funke (2016) created and validated a new measure of authoritarianism called the Aggression-Submission-Conventionalism (ASC) scale. Dunwoody and Funke acknowledged the largely intellectual focus of the ASC scale and its inability to capture emotional aspects of authoritarianism as one of its limitations. So far, this new scale has been used in only one empirical study in the field of political psychology, focusing on prejudice against minority populations, and due to its limitations, the authors had to combine it with RWA scale (see Dunwoody & McFarland, 2018). Thus, the ASC scale lacks empirical support that would warrant its use in studies of uncertainty orientation. Hence, the Cherry and Byrne scale, despite its limitations, was a reasonable choice for this study. With this study, I intended to build on the research on uncertainty orientations as conceptualized by Sorrentino and collaborators and used the same measures that have been well-tested in uncertainty orientation research over the past 30 years. Participants did not raise any prompt-related questions or questions, either during or after the administration of this measure.

Data Analysis

The first step in data analysis was the analysis of the uncertainty orientation measures. Then, I used the results of this analysis to assign participants into collaborative groups. I
analyzed other data upon completion of all the collaborative STEM tasks and related data collection. The flow of data collection and analysis is illustrated in Figure 3.2.

Figure 3.2. Data collection and analysis.

Analysis of uncertainty orientation measures. I organized all the data collected via Qualtrics into participant folders on a university provided secure network drive (i.e., OneDrive). During this process, I followed the guidance of the institution’s Information Technology
department and the IRB to ensure data security and integrity. Only authorized personnel were allowed access to the data. Prior to the analysis, all participants’ essays were exported into Word and all survey responses were exported into Excel.

**The nUncertainty measure.** According to the guidelines provided in the Sorrentino, Hanna, et al. (1992) scoring manual, the first step in scoring each story was to determine the presence of need for uncertainty imagery. Researchers determined the presence of the need to approach uncertainty imagery based on the following five criteria: (a) story includes a definite statement about the character of the story resolving some uncertainty to achieve a desired outcome; (b) the character seeks to clarify or learn more about some unknown; (c) the character expresses a concern over dissonant ideas and seeks to resolve the discrepancy; (d) the character expresses a concern over a discrepancy between an event and an existing cognitive structure and seeks to resolve it; (e) the character expresses a concern about the dissonance between an idea and her or his behavior and attempts to deal with it (Sorrentino, Hanna, et al., 1992).

If the need to approach uncertainty imagery is not present in the story, Sorrentino, Hanna, et al. (1992) recommended that the story should be classified as either presenting doubtful imagery or unrelated imagery. The doubtful imagery designation means that the participant included some references to the resolution of uncertainty but failed to meet the criteria listed above. An additional possibility was that uncertainty was present in the story but the character neither approached, nor avoided it, or that the ending of the story was in some way bizarre. Such stories also received a score of doubtful imagery. The unrelated imagery designation means that the character began resolving uncertainty but then gave up, approached uncertainty as a result of being coerced by another character in the story, or avoided approaching uncertainty altogether.
For stories classified as containing doubtful imagery or unrelated imagery, no additional scoring is possible (Sorrentino, Hanna, et al., 1992).

Stories identified as containing the need to approach uncertainty imagery warranted additional examination for subcategories (Table 3.4; Sorrentino, Hanna, et al., 1992). Sorrentino, Hanna, et al. (1992) identified the following subcategories: (a) stated need to master; (b) instrumental activity; (c) goal anticipation; (d) blocks in the person or in the world; (e) nurturant press; (f) positive and negative affective states; and (g) thema. Upon completion of identifying subcategories, the following numerical scores were assigned: (a) -1, for a story scored as unrelated imagery; (b) 0, for a story scored as doubtful imagery, and (c) 1, for a story scored as need to approach uncertainty, with an additional point given for each identified subcategory. A participant’s total $n$Uncertainty score was based on the aggregated imagery score for the four stories. For example, if a participant scored -1, 0, 3, and 4 then a total aggregated $n$Uncertainty score would be 6.
### Table 3.4

**Scoring Subcategories for Stories with Identified Need for Uncertainty**

<table>
<thead>
<tr>
<th>Subcategory name</th>
<th>Short code</th>
<th>Description</th>
<th>Example</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stated need to master uncertainty</td>
<td>N</td>
<td>A character expresses a need or a desire related to the goal of approaching or mastering uncertainty.</td>
<td>“The young person must continue looking for answers.”</td>
<td>May be scored only once in a story</td>
</tr>
<tr>
<td>Instrumental activity</td>
<td>I (+/?/-)</td>
<td>Character takes overt or covert activities towards attaining the goal of approaching or mastering uncertainty. +/?/- denotes the net effect of the action on the outcome of the story (successful, doubtful, or unsuccessful).</td>
<td>“She is seeking the solution for the problem.”</td>
<td>May be scored only once in a story</td>
</tr>
<tr>
<td>Goal anticipation</td>
<td>Ga (+/-)</td>
<td>A character anticipates goal attainment or failure. + denotes a character in a story thinking about positive outcomes of uncertainty resolution. – denotes a character is doubtful or concerned about failure.</td>
<td>“She thinks she can resolve the mystery”</td>
<td>Ga+ and Ga- may be scored once each per story.</td>
</tr>
<tr>
<td>Blocks in the person</td>
<td>Bp</td>
<td>Progress in goal directed activity is hindered due to the previous failure to resolve uncertainty or due to a factor within a character (i.e., lack of confidence or skill).</td>
<td>“He didn’t know how to use the software to solve the problem.”</td>
<td>May be scored only once in a story</td>
</tr>
<tr>
<td>Blocks in the world</td>
<td>Bw</td>
<td>Progress in goal directed activity is hindered due to the environment (i.e., interruptions by other people).</td>
<td>“She ran out of time to solve the problem.”</td>
<td>May be scored only once in a story</td>
</tr>
<tr>
<td>Nurturant press</td>
<td>Nup</td>
<td>Forces in the story help the character in reaching a goal of resolving uncertainty. Excludes handing the problem to someone else – such a story would be scored UL.</td>
<td>“His older colleague provided the additional evidence he needed”</td>
<td>May be scored only once in a story</td>
</tr>
<tr>
<td>Affective states</td>
<td>G (+/-)</td>
<td>Refers to the affected states related with the goal achievement. Character experiences feelings of relief, satisfaction, or confidence upon resolving uncertainty (G+). Character experiences feelings of depression, anxiety or failure upon resolving uncertainty (G-).</td>
<td>“She was fascinated by what she learned!”</td>
<td>Ga+ and Ga- may be scored once each per story.</td>
</tr>
<tr>
<td>Thema</td>
<td>Th</td>
<td>Resolution of uncertainty is the central plot of the story and a key motivational source.</td>
<td></td>
<td>Score independently of other subcategories. Score only if there are no competing motivations or subplots.</td>
</tr>
</tbody>
</table>

Prior to the data collection, in preparation for the scoring of the Uncertainty measure, both myself and another scorer (i.e., Scorer 1), with expertise in essay and SRL coding, trained using the practice materials for uncertainty orientation scoring (C. P. Smith & Franz, 1992). The scorer training involved the analysis and discussion of the expert scoring provided in the practice materials, as well as scoring of practice stories. During this training, we each independently scored a total of 64 practice stories. We met multiple times to review our practice scoring and achieved interrater agreement of approximately 80%. We resolved all scoring discrepancies through discussion.

Scoring of the live data involved scoring a total of 72 stories (i.e., four stories for each of the 18 participants) over the course of five days. A quick turnaround was paramount because participants’ group assignment depended on the availability of participants uncertainty orientation scores. We achieved interrater agreement of around 78%. We met on four separate occasions to discuss scoring discrepancies and came to a 100% agreement establishing a reconciled score for each story.

*The measure of authoritarianism.* As previously described, the second measure, based on Cherry and Bryne (1977) acquiescence-free measure of authoritarianism, was a 21-item self-report measure (see Figure 3.1) with a 6-point Likert-like scale, ranging from -3 (I disagree very much), to +3 (I agree very much). This measure addressed participants’ orientations toward certainty (Sorrentino, Roney, et al., 1992). I exported participants’ responses from Qualtrics survey into Excel and then used SPSS for subsequent analysis. Items 7, 8, 11, 12, 14, 15, 17, 18, 19, and 21 were reverse scored. I summed up participant responses and created the measure of authoritarianism score for each participant.
**Resultant uncertainty orientation score.** According to the guidelines presented in the uncertainty orientation scoring manual (Sorrentino, Hanna, et al., 1992) and utilized in empirical studies of uncertainty orientations (e.g., Shuper & Sorrentino, 2004; Szeto et al., 2011), I calculated the resultant uncertainty orientation score by transforming the score on each measure into a z-score and subtracting the authoritarianism z-score from the uncertainty z-score. Finally, I identified tertile splits of the resultant uncertainty scores. Participants with resultant uncertainty scores in the highest tertile were characterized as UO, whereas participants in the lowest tertile were characterized as CO. Participants in the middle tertile were categorized as moderately oriented toward uncertainty. UOs were relatively high in uncertainty and low in authoritarianism, COs were relatively low in uncertainty and high in authoritarianism, and moderates were either high or low on both dimensions.

**Sociocultural discourse analysis.** Prior to the start of the analysis, I obtained transcripts of all video recordings by using an outside professional transcription firm (i.e., rev.com), approved by the IRB. To understand participants’ experiences in this study, I used sociocultural discourse analysis, which is particularly well-suited for the analysis of collaborative group work in the classroom (Mercer, 2004, 2010) and regulatory processes that occur within collaborative sessions (Grau & Whitebread, 2012). Sociocultural discourse analysis is based on Vygotsky’s conception of language as a psychological and cultural tool (Vygotsky, 1978). Due to the emphasis on group discourse as a “social mode of thinking” (Mercer, 2004, p. 137), sociocultural discourse analysis differs from other types of discourse analysis in which investigators focus on linguistic structures with text and tend to rely on quantitative analysis of word occurrences. In contrast, researchers using sociocultural discourse analysis are less concerned with the language, and more with its dynamic function and meaning during joint construction of knowledge in a
given context and over time (Mercer, 2004, 2010). Researchers using sociocultural discourse analysis might rely on both qualitative analysis of discourse and quantitative analysis (i.e., frequencies) of occurrences of certain “key words” (Mercer, 2010, p. 9) to identify important episodes and describe a phenomenon of interest.

**Quantitative analysis plan.** Through a review of literature (Crismore & Vande Kopple, 1997; Kirch & Siry, 2012; Lakoff, 1973; Yang, 2013), I created the initial list of 116 discourse markers. This broad list included markers of uncertainty that appear more often in written than in spoken language. So, next, I read transcripts of groups’ dialogues and eliminated expressions and phrases that were not used in the classroom discourse (e.g., as a manner of speaking, to a certain degree, etc.). Next, I added several phrases that participants used when they were expressing personal uncertainty (e.g., I don’t know, I wonder, etc.). The final list of the 60 discourse markers of uncertainty I used in this study and the related number of their occurrences are shown in Appendix B. Of the 60 markers that I searched for, 30 occurred at least once in the transcripts of groups’ discourse.

**Qualitative analysis plan.** Following Mercer’s (2004) advice, I originally intended to include students’ nonverbal communications in my analysis (i.e., observable gesturing, facial expressions, etc.). Consistent with recommendations by Denham and Onwuegbuzie (2013), I proposed to code nonverbal communication within regulative episodes to (a) corroborate verbal narrative; (b) complement verbal communication; (c) discover nonverbal behaviors that contradict the verbal communication; (d) expand the scope of my understanding; or (e) create new directions based on additional insights. For example, if the analysis of groups’ discourse indicates that there is an episode of SSRL happening, then group members’ smiling and nodding would be coded with the “corroborate” code, to indicate that non-verbal gestures corroborated
spoken text. My original intent was that myself and one additional coder (i.e., Coder 2) with expertise in coding of social regulation of learning would code all of the data involving social regulation of learning. However, due to the Coder 2 being a member of an external institution, the IRB limited Coder 2’s access to only depersonalized data (i.e., transcriptions only, no video). This limitation caused me to make a change to the original plan and relegate the coding of the non-verbal data to a future study.

My data analysis procedures had two levels. At Level 1 of analysis, myself and one additional coder (i.e., Coder 1) individually watched videos of groups’ work and wrote analytic memos (Miles, Huberman, & Saldaña, 2014) about each video. The analytic memos included descriptions of general group climate and dynamics, common regulation processes and targets of regulation, and specific group members as regulation participants. We paid special attention to the occurrences of the discourse markers of uncertainty in groups’ dialogue and how they related to the episodes of social regulation of learning that unfolds during groups’ work. Hence, in this study, I used discourse markers in the sense of Mercer’s (2004) key words and marked the critical episodes in the videos related to uncertainty identified, articulated, or addressed in some way by group members.

We marked such episodes by logging their time stamps in the analytic memos, so that we could easily return to them later or in Level 2 of the analysis. We met to compare our memos, and discuss our assertions and propositions related to each of the research questions in order to synthesize the findings from this level of analysis about each video and about each of the three groups (Miles et al., 2014). Preparation of the analytic memos and development of assertions and propositions helped with the identification of relevant data that I used to look within and across the groups for patterns, similarities, and differences, as I began to answer my research questions.
Level 2 of the data analysis involved deductive and inductive coding (Miles et al., 2014) at the level of regulative episode of the transcribed video-recordings of collaborative inquiry sessions. For the purpose of this study, I defined regulative episode as a series of participants’ talk turns in which they engaged in observable regulation of learning at the individual, peer, or group level or in which a person external to the group (e.g., the instructor) regulated participants’ learning. I defined non-regulative episodes as a series of participants’ talk turns in which the group did not engage in regulation of learning (i.e., off-task interactions, construction of knowledge, etc.). I did not analyze non-regulative episodes. Other researchers (e.g., Rogat & Linnenbrink-Garcia, 2011) have found that off-task discussions are associated with group dynamics during on-task engagement; thus, I developed short narrative summaries to describe off-task student discourse and noted the specific start and end time when it occurred (e.g., 10:35 AM to 10:45 AM A ten-minute conversation about the upcoming mid-term exams). I used these summaries to gain additional insight into groups’ dynamics and track their time off-task.

In terms of the actual coding, first, coders jointly identified regulative and non-regulative episodes in transcripts. Then, both coders separately coded regulative episodes for the following: (a) modes of social regulation of learning, (b) regulative processes, (c) regulative targets, (d) learning strategies, and (e) socio-emotional interactions. We started with deductive coding based on the codebook (see Tables 3.5, 3.6, and Appendix C) that I developed based on my previous work and the existing SSRL literature (Dragnic-Cindric et al., 2018; Grau & Whitebread, 2012; Rogat & Linnenbrink-Garcia, 2011). For every regulative episode, coders assigned a primary code for the dominant mode of regulation of learning (i.e., SSRL, coRL, SRL, or external regulation) identified in the episode. Then, within each episode, coders assigned appropriate codes to further discern additional modes of regulation embedded within the episode and
regulative processes with their targets, as well as learning strategies and socio-emotional interactions. As expected, during coding, new codes emerged from participants’ discourse and behavioral patterns (Miles et al., 2014). We discussed and refined these inductive codes and added them to the codebook. We went back to the previously coded episodes to determine if the newly identified codes applied to them. We achieved interrater agreement of 98% for the modes of regulation (i.e., primary codes), and around 85% agreement for all secondary and tertiary codes. All disagreements were resolved through discussion. (i.e., 100% reconciled agreement). Figure 3.3 illustrates this process with an example from previous work. A combination of deductive and inductive coding in Level 2 data analysis, in addition to the Level 1 analytic memos and summaries, provided a solid base for development of rich, in-depth qualitative descriptions of findings for each research question.
Table 3.5

*Codebook for Social Regulation of Learning: Primary Codes*

<table>
<thead>
<tr>
<th>Type</th>
<th>Code</th>
<th>Description with empirical indicators</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of social regulation of learning</td>
<td>SRL</td>
<td>A group member regulates her or his own cognition, behavior, motivation or emotions: a group member identifies something she or he does not understand, needs to do, or has done related to the learning task. Emphasis is on the word <em>I</em>.</td>
<td>Group member 1: “I need to read this again. I don’t know what she wants us to do”</td>
</tr>
</tbody>
</table>
|                               | CoRL | One or multiple group members temporarily guide regulation of one or multiple other members in the group: a group member prompts others to engage in the task or explains how they think the group should proceed on the task. Other members acknowledge the effort or the idea but do not contribute anything new to the discourse. Emphasis is on the word *you*. | Group member 1: “Hey, turn around, we need you to pay attention here. Just ignore them.”  
Group member 2: “Ok, I’ll try.” |
|                               | SSRL | Group members collectively regulate the group’s learning: Ideas and contributions of a group member are followed by uptake and contributions from at least one other group member. Emphasis is on the word *we* or collective *you*.                      | Group member 1: “Why don’t we share what we think is the best way to design a bioreactor?”  
Group member 2: “Yeah, let’s make a table with ingredients we think should be in it.” |
| Other modes of regulation     | External Regulation | Someone outside the group (i.e., teacher) temporarily guides regulation of one or multiple members of the group: someone outside of the group monitors the progress and understanding, prompts group members to engage in the task, or explains how they think the group should proceed on the task. Group members acknowledge the effort or the idea but do not contribute anything new to the discourse. Emphasis is on the word *you*. | Teacher: “Have you all picked the best model and answered each question?”  
Group member 1: “Yeah, almost done.” |

*Note.* SRL = Self-regulated learning; CoRL = Co-regulated learning; SSRL = Socially-shared regulated learning.
**Table 3.6**

*Codebook for Social Regulation of Learning: Secondary Process and Strategy Use Codes*

<table>
<thead>
<tr>
<th>Secondary code</th>
<th>Description with empirical indicators</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>Task appraisal and decision making:</td>
<td>“Let’s talk about best design for this container!”</td>
</tr>
<tr>
<td></td>
<td>Reading and interpreting task directions,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>designating task assignments and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>responsibilities for each team member,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>planning the resources need to carry out the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>task, or discussing the overall goal or sub-goals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>for the task at hand.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>It may involve reading and interpreting relevant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>science content and relating it to the task at</td>
<td></td>
</tr>
<tr>
<td></td>
<td>hand. Discussing how the content relates to the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>completion of the task.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>“We need to figure out the best mix of greens and browns for the bioreactor.”</td>
<td></td>
</tr>
<tr>
<td>Monitoring</td>
<td>Monitoring various aspects of cognition,</td>
<td>“This should be easy – I have built parachutes with my little brother.”</td>
</tr>
<tr>
<td></td>
<td>metacognition, motivation, affect, or behavior:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>It may include judgements of understanding,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>judgements of knowing, feeling of knowing,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>judging the quality of groups’ work,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>monitoring time remaining for task completion,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>monitoring behaviors etc.</td>
<td></td>
</tr>
<tr>
<td>Controlling</td>
<td>Enacting change upon detected dissonance</td>
<td>“OK, that will fall down.</td>
</tr>
<tr>
<td></td>
<td>during monitoring:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>It may include abandoning an ineffective</td>
<td></td>
</tr>
<tr>
<td></td>
<td>problem approach or a strategy, changing or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>abandoning previously set goals, or trying to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>change someone’s behavior etc.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Let’s try making the base of the tower wider. (Control) “</td>
<td></td>
</tr>
<tr>
<td>Evaluating</td>
<td>Evaluations of the plan, task completion,</td>
<td>Group member 1: “I don’t think this design worked for us. This bioreactor smells so bad.”</td>
</tr>
<tr>
<td></td>
<td>content understanding, effectiveness of the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>used strategies, or achievement of goals.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Group member 2: “Yeah, there was too much moisture in the greens. We forgot about that.”</td>
<td></td>
</tr>
<tr>
<td>Strategy Use</td>
<td>Use of a specific strategy:</td>
<td>“For the poster, we should include the mass for each ingredient we put into our bioreactor.”</td>
</tr>
<tr>
<td></td>
<td>It may include taking notes, summarizing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>groups notes, re-reading task instructions or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>content materials, selecting what to include in</td>
<td></td>
</tr>
<tr>
<td></td>
<td>groups work products etc.</td>
<td></td>
</tr>
</tbody>
</table>
First, I utilized quantitative analysis of qualitative coding, that is the frequency counts of the regulation codes, to discern general trends in groups’ regulative behaviors. Then, to present a more complete picture of groups’ social regulation of learning, and describe interactions among the group members, I used qualitative sociocultural discourse analysis of groups’ dialogues. Additionally, quantitative and qualitative analysis of the video data was complemented with analysis of the secondary data sources and modes of evidence including, participants’ reflective blogs, responses to pre-task questions, observational field notes, and group created artifacts. Triangulation of different sources and modes of data provided support for the findings from discourse analysis or pointed to inconsistencies and indicated a need for a closer re-examination of different sources of data (Miles et al., 2014). I analyzed preservice teachers’ reflective blogs to potentially gain insight into their individual perceptions about the encountered uncertainty, tasks,
group dynamics, and groups’ joint learning. I reviewed field notes for additional data about
groups’ interactions and regulation of learning as they encountered challenges during scientific
inquiry. Groups’ artifacts were examined to determine whether they provided additional
evidence about how groups articulated and addressed scientific uncertainty and task complexity
encountered during inquiry. Integrating findings from different sources and modes of data allows
for the building of a multi-dimensional perspective of the phenomenon of interest and serve to
enhance the trustworthiness of the study (Miles et al., 2014). I present a summary of research
questions and data that I used to address each question and data analysis in Table 3.7.

Table 3.7

<table>
<thead>
<tr>
<th>Research question</th>
<th>Data</th>
<th>Data analysis focused on interactions among social regulation of learning, uncertainty, and inquiry</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. How do collaborative groups of elementary preservice elementary school teachers regulate their learning when they encounter scientific uncertainty inherent in the task?</td>
<td>Video recording, Participants’ responses to the open-ended question about task expectations, Participant’s individual blogs, Group created artifacts, Field notes</td>
<td>Discourse analysis, Analysis of the responses w/ inductive coding, Analysis of reflective blogs, Analysis of groups’ artifacts, Analysis of field notes</td>
</tr>
<tr>
<td>2. How does preservice elementary school teachers’ enactment of social regulation of learning vary with respect to differences in the degree of situational uncertainty encountered during collaborative inquiry tasks?</td>
<td>Video recording, Participants’ responses to the open-ended question about task expectations, Participant’s individual blogs, Group created artifacts, Field notes</td>
<td>Discourse analysis, Analysis of the responses w/ inductive coding, Analysis of reflective blogs, Analysis of groups’ artifacts, Analysis of field notes</td>
</tr>
<tr>
<td>3. How does regulation of learning during collaborative inquiry differ for people of different uncertainty orientations?</td>
<td>Video recording, Measures of uncertainty orientation, Participants’ responses to the open-ended question about task expectations, Participant’s individual blogs, Group created artifacts, Field notes</td>
<td>Discourse analysis, Quantitative analysis of uncertainty orientation measures, Analysis of the responses w/ inductive coding, Analysis of reflective blogs, Analysis of groups’ artifacts, Analysis of field notes</td>
</tr>
</tbody>
</table>
Methodological Integrity

In this multimethod study, I relied on both quantitative and qualitative analysis of the qualitative data to illuminate processes of social regulation of learning when learners encounter uncertainty. However, the main focus of my study was the contextualized qualitative analysis of groups’ regulation of learning. C. Marshall and Rossman (2016) posited a continuum of qualitative studies ranging from artistic and impressionist approaches at one end, over middle-grounded approaches, to the realist approaches, reflective of positivist stance, at the other end. In the present study, I took the middle ground approach to qualitative studies, suitable for studies in which researchers attempt to generate descriptions and understanding of phenomena by relying on observations of participants. To ensure authenticity of my study, I used multiple strategies: triangulation of multiple data sources and collection of rich data, spending prolonged time in the field, clarification and disclosure of my own biases, peer debriefings, use of multiple coders and, finally, reporting my findings through the use of participants’ own words (Creswell, 2014; Gall et al., 2007). I also looked for disconfirming cases within the corpus of data that might have challenged and disconfirmed my interpretations (Gall et al., 2007). In this study, triangulation of multiple sources of data included utilizing video recording of the small group collaboration, preservice teachers’ pre-task responses, reflective blogs, uncertainty orientation measures, as well as field observation notes, and artifacts of group work. I collected field observation notes to capture what was going on in the whole classroom and in small groups in a format that explicitly distinguished between observations and observer comments (Figure 3.4), as suggested by C. Marshall and Rossman (2016). Spending prolonged time in the classroom, beyond the time that groups took to complete inquiry tasks, enabled me to develop a deeper understanding of the
social regulation of learning that unfolds during groups’ collaborative work, further contributing to the credibility of my findings (Creswell, 2014).

<table>
<thead>
<tr>
<th>Class Start Time: 8:10am</th>
<th>Observation</th>
<th>Observer’s Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:10 AM</td>
<td>The class starts with students measuring and observing changes in their bioreactors. One of the students from group 1 asks peers if it is normal for the material in the bioreactor to look moldy. Others at the table lean in to look at her bioreactor. Then they start examining their own bioreactors. Instructor reminds the class about their visit to the garden where the garden attendant has told them that there is a peak temperature.</td>
<td>Group 2: very quiet today and they look upset. I wonder if anything happened prior to our class to upset them.</td>
</tr>
<tr>
<td>8:20 AM</td>
<td>The screen is displaying Final Unit Project slide and the instructor is giving the directions.</td>
<td></td>
</tr>
</tbody>
</table>

*Figure 3.4. Field observation notes template with a hypothetical example.*

I wrote reflective memos during the data collection phase to keep track of my own positionality and biases (Creswell, 2014; Gall et al., 2007). I also engaged in periodic debriefings with peers and advisors in relevant fields (i.e., SRL, science education) to ensure that my interpretations were well grounded in data (Gall et al., 2007; C. Marshall & Rossman, 2016). Finally, I reported my findings using excerpts from groups’ discourse, providing readers with an opportunity to experience groups’ interactions through the participants’ own words and in that sense share in the participants’ experience (C. Marshall & Rossman, 2016).
CHAPTER 4: FINDINGS

In this multimethod, exploratory study, I examined social regulation of learning that occurs when groups of preservice elementary school teachers of different uncertainty orientations engage in a series of five science inquiry tasks requiring them to grapple with the encountered uncertainty. I started this research study intending to examine the following three research questions:

- Research Question 1: How do collaborative groups of preservice elementary school teachers socially regulate their learning when they encounter scientific uncertainty inherent in the task?
- Research Question 2: How does preservice elementary school teachers’ enactment of social regulation of learning vary with respect to differences in the degree of situational uncertainty encountered during collaborative inquiry tasks?
- Research Question 3: How does regulation of learning during collaborative inquiry differ for people of different uncertainty orientations?

However, after many rounds of data analysis, it became apparent that it was not possible to discuss identified differences in groups’ regulation of learning that were moderated by the task uncertainty levels separately from those that were due to the differences in the uncertainty orientations of the groups. For example, my findings about groups’ on- and off-task engagement spanned groups’ uncertainty orientations and task uncertainty levels. Discussing such findings from just one of the two perspectives (e.g., uncertainty orientation) would have been insufficient
because it would have privileged the role of that perspective and obscured the role of the other (e.g., task uncertainty level) in groups’ social regulation of learning. Hence, I merged Research Questions 2 and 3 into the following single research question:

Research Question 2: How does preservice elementary school teachers' enactment of social regulation of learning during collaborative inquiry vary with respect to the degree of situational uncertainty in the task and the uncertainty orientation of the group?

This new Research Question 2 enabled me to avoid unwarranted fragmentation and inadvertent distortion of the findings and allowed for a coherent presentation of groups’ regulation of learning.

In this chapter, I describe the structure of the collaborative groups purposefully selected to ensure maximum variability in terms of the group members’ uncertainty orientations. Then, I describe detailed findings for each of the two research questions. For the purpose of this study, I defined on-task engagement as the time during which the group actively worked on the task at hand in front of the stationary camera, excluding all off-task conversations among the group members. On-task engagement also excluded idle times during the instructor-led whole-class task instructions or reporting out by other groups. Defining the on-task engagement in this way enabled me to focus on times when observed groups had opportunities to actively regulate their learning if needed, and that could be assessed through the coding and analysis of the transcripts of group members’ interactions.

To present a more complete picture of groups’ social regulation of learning relative to both research questions, I relied on quantitative analysis of coding for regulative processing, that is the frequency counts of the regulation codes. I reported both the raw counts and normalized frequency counts for observed codes of regulatory processes and socio-emotional interactions.
Raw counts represent the number of times each code occurred during a particular collaborative session. Normalized frequency counts are raw counts divided by the duration of groups’ on-task engagement. For example, if a code occurred 20 times during a collaborative session (i.e., raw count was 20) and the session lasted 10 min, then a normalized frequency count would be two. Both raw and normalized counts are helpful for describing groups’ regulation because it is possible for groups to end up with same overall raw counts or with the same normalized frequency counts despite spending different amounts of time on task, or with different overall counts and different normalized frequency counts even though their on-task time was the same. Although I used quantitative analysis to complement my qualitative analysis, the main focus of my study was the contextualized thematic analysis of groups’ regulation of learning.

**Collaborative Group Structure**

Following the process described in the previous section, I assigned participants to collaborative groups based on their uncertainty orientations and field placement grade levels. Then, I purposefully selected three groups for observation and video recording ensuring maximum within-group and across-group variability. I selected a group with a majority of members who were UO, a group with a majority of members who were CO, and a group with mixed uncertainty orientation participants (i.e., two moderates, one UO, one CO; Table 4.1). The UO participant and the CO participant in the Mixed group were the participants whose uncertainty orientation scores fell on the two ends of the scale; the UO participant had the highest resultant uncertainty orientation score (i.e., the most UO participant) and the CO participant had the lowest resultant uncertainty orientation score (i.e., the most CO participant). I placed the participants with the most extreme uncertainty orientation scores in the group with the two moderates to ensure a maximum variability of uncertainty orientations within the group.
Table 4.1

*Observed Collaborative Group Structure*

<table>
<thead>
<tr>
<th>Group</th>
<th>Uncertainty Orientation</th>
<th>Field Placement Grade Level</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td>UO Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emma UO</td>
<td>UO</td>
<td>4</td>
<td>Female</td>
</tr>
<tr>
<td>Julie UO</td>
<td>UO</td>
<td>3</td>
<td>Female</td>
</tr>
<tr>
<td>Sarah UO</td>
<td>UO</td>
<td>3</td>
<td>Female</td>
</tr>
<tr>
<td>Rose UO</td>
<td>UO</td>
<td>3</td>
<td>Female</td>
</tr>
<tr>
<td>CO Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laura CO</td>
<td>CO</td>
<td>4</td>
<td>Female</td>
</tr>
<tr>
<td>Alice CO</td>
<td>CO</td>
<td>3</td>
<td>Female</td>
</tr>
<tr>
<td>Kerry CO</td>
<td>CO</td>
<td>3</td>
<td>Female</td>
</tr>
<tr>
<td>Parker</td>
<td>moderate</td>
<td>3</td>
<td>Female</td>
</tr>
<tr>
<td>Mixed Group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stella</td>
<td>UO</td>
<td>2</td>
<td>Female</td>
</tr>
<tr>
<td>Jane CO</td>
<td>UO</td>
<td>2</td>
<td>Female</td>
</tr>
<tr>
<td>Tom</td>
<td>moderate</td>
<td>1</td>
<td>Male</td>
</tr>
<tr>
<td>Kate</td>
<td>moderate</td>
<td>1</td>
<td>Female</td>
</tr>
</tbody>
</table>

*Note.* UO = Uncertainty-oriented. CO = Certainty-oriented.

**Most Salient Qualitative Themes**

In this study, my aim was to examine and describe interactions among social regulation of learning, uncertainty, and collaborative tasks for three groups of preservice elementary school teachers with different uncertainty orientations. I found three themes that were similar for all three groups, thus addressing the first research question. With regard to the second research question, I found three unique salient themes for each group, totaling nine themes related to the regulation of learning in response to the uncertainty experienced through the series of five
collaborative tasks (Figure 4.1). Next, I discuss quantitative and qualitative findings for each research question.

**Figure 4.1.** A summary of salient themes by group.

**Findings for Research Question 1**

Research Question 1: How do collaborative groups of preservice elementary school teachers socially regulate their learning when they encounter scientific uncertainty inherent in the task?

**Regulative episodes and modes of regulation.** Coders identified a total of 291 episodes over the course of five inquiry tasks across the three groups, of which approximately 78% were regulative episodes. Other episodes were off-task episodes, whole-class debriefings, or episodes of students simply working on the task without the need to engage in regulation of learning. Engaging in regulation or not is a group’s regulative choice, as is on- and off-task engagement. Although it is possible that a longer task duration might result in a greater number of regulative episodes, it is also possible for a group to work on a task for the same amount of time and have
zero regulative episodes. Thus, in this study, I relied on the average number of episodes and modes of regulation across episodes within a task as an adequate measure for describing groups’ engagement in regulation of learning in a classroom setting.

On average, groups engaged in 15 regulative episodes per collaborative session (Table 4.2). First, I looked at the dominant mode of regulation per episode, keeping in mind that, according to Hadwin et al. (2018), a regulative episode may contain other modes of regulation embedded within it (i.e., an instance of SRL might occur within an SSRL episode). For all three groups, SSRL was the most frequent dominant social mode of regulation of learning assigned to the episodes, followed by coRL and then SRL. External regulation of learning, which refers to regulation by someone outside of the group (i.e., the course instructor or the teaching assistant), accounted for approximately 15% of groups’ regulative episodes.

Table 4.2

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of episodes (M)</th>
<th>SSRL (%)</th>
<th>coRL (%)</th>
<th>SRL (%)</th>
<th>External regulation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UO Group</td>
<td>16.8</td>
<td>76.2%</td>
<td>8.3%</td>
<td>0.0%</td>
<td>15.5%</td>
</tr>
<tr>
<td>CO Group</td>
<td>16.6</td>
<td>66.3%</td>
<td>16.9%</td>
<td>2.4%</td>
<td>14.5%</td>
</tr>
<tr>
<td>Mixed Group</td>
<td>12</td>
<td>80.0%</td>
<td>5.0%</td>
<td>1.7%</td>
<td>13.3%</td>
</tr>
<tr>
<td>Average</td>
<td>15.1</td>
<td>73.6%</td>
<td>10.6%</td>
<td>1.3%</td>
<td>14.5%</td>
</tr>
</tbody>
</table>


Next, to gain a full understanding of the modes of regulation that occurred during groups’ learning, it was important to consider the overall frequency of occurrences for each mode of regulation across all episodes. Across all groups, coders identified an average of 23 instances of various modes of regulation per collaborative session (Table 4.3).
Table 4.3

*Frequency of Modes of Regulation Across Regulative Episodes*

<table>
<thead>
<tr>
<th>Group</th>
<th>Count (M)</th>
<th>SSRL (%)</th>
<th>coRL (%)</th>
<th>SRL (%)</th>
<th>External regulation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UO Group</td>
<td>24.6</td>
<td>56.1%</td>
<td>7.3%</td>
<td>11.4%</td>
<td>25.2%</td>
</tr>
<tr>
<td>CO Group</td>
<td>28.8</td>
<td>38.9%</td>
<td>11.8%</td>
<td>32.6%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Mixed Group</td>
<td>16.6</td>
<td>57.8%</td>
<td>6.0%</td>
<td>4.8%</td>
<td>31.3%</td>
</tr>
<tr>
<td>Average</td>
<td>23.3</td>
<td>49.4%</td>
<td>8.9%</td>
<td>18.6%</td>
<td>23.1%</td>
</tr>
</tbody>
</table>


This closer look at the regulative modes, which surpassed the dominant mode assigned to each episode to consider modes embedded within it, revealed that for the UO and Mixed groups, modes of regulation enacted on the group level (i.e., SSRL and coRL) were more prevalent (approximately 64%) than modes of regulation involving the individual level (i.e., SRL) or external regulation of learning (approximately 36%). For the CO group, a more even balance existed between group-level regulation modes (approximately 51%) and individual and external regulation (49%). This finding indicates that the UO and Mixed groups engaged more in social regulation of learning, whereas the CO group relied more on individual SRL and external regulation from the instructor.

**Regulative processes and targets.** Coders identified an average of 229 regulative processes per collaborative session. Of the four macro-regulative processes, which include planning, monitoring, controlling, and evaluating, all three groups engaged the most in monitoring, which accounted for approximately 70% of all regulative codes, and the least in evaluating, which accounted for close to 3% of all regulative codes (Table 4.4). UO and CO groups engaged in more controlling than planning, whereas the Mixed group enacted more planning than controlling.
Table 4.4

Frequency Counts for Regulative Macro-Processes across Five Tasks

<table>
<thead>
<tr>
<th>Group</th>
<th>Raw count (M)</th>
<th>Planning (%)</th>
<th>Monitoring (%)</th>
<th>Controlling (%)</th>
<th>Evaluating (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UO Group</td>
<td>274.0</td>
<td>8.9%</td>
<td>70.6%</td>
<td>17.8%</td>
<td>2.7%</td>
</tr>
<tr>
<td>CO Group</td>
<td>223.2</td>
<td>12.1%</td>
<td>67.3%</td>
<td>16.2%</td>
<td>4.4%</td>
</tr>
<tr>
<td>Mixed Group</td>
<td>190.6</td>
<td>15.6%</td>
<td>70.8%</td>
<td>11.2%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Average</td>
<td>229.3</td>
<td>11.8%</td>
<td>69.6%</td>
<td>15.5%</td>
<td>3.1%</td>
</tr>
</tbody>
</table>

Note. UO = Uncertainty-oriented. CO = Certainty-oriented.

A closer look at the regulative targets (i.e., what the groups regulated) revealed that virtually all the planning codes referred to task planning, with only two occurrences of content planning occurring across all groups and tasks. This finding suggests that students were mostly concerned with how to complete the task rather than with what they could learn from it. In monitoring, four codes accounted for 90% of all monitoring codes (Table 4.5).

All groups engaged the most in the monitoring of the task plan (MTP), followed by the monitoring of task understanding (MTU), and monitoring progress (MP). The groups invoked monitoring of content understanding (MCU) the least. These findings regarding the most frequent monitoring processes mirrored the findings regarding planning: participants seemed mostly concerned with regulating the task as opposed to regulating the content.

Table 4.5

Most Prominent Monitoring Codes as a Percentage of Total Monitoring

<table>
<thead>
<tr>
<th>Group</th>
<th>Monitoring code count (M)</th>
<th>MTP (%)</th>
<th>MTU (%)</th>
<th>MP (%)</th>
<th>MCU (%)</th>
<th>Other (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UO Group</td>
<td>193.4</td>
<td>42.7%</td>
<td>21.0%</td>
<td>18.0%</td>
<td>8.0%</td>
<td>10.3%</td>
</tr>
<tr>
<td>CO Group</td>
<td>150.2</td>
<td>34.1%</td>
<td>29.7%</td>
<td>18.8%</td>
<td>8.1%</td>
<td>9.3%</td>
</tr>
<tr>
<td>Mixed Group</td>
<td>135.0</td>
<td>34.8%</td>
<td>29.8%</td>
<td>16.9%</td>
<td>10.2%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Average</td>
<td>159.5</td>
<td>37.8%</td>
<td>26.2%</td>
<td>17.9%</td>
<td>8.7%</td>
<td>9.4%</td>
</tr>
</tbody>
</table>

Note. UO = Uncertainty-oriented. CO = Certainty-oriented. MTP = Monitoring task plan. MTU = Monitoring task understanding. MP = Monitoring progress. MCU = Monitoring content understanding.
Similarly, in controlling, students focused primarily on controlling the task plan (CTP); this code accounted for approximately 83% of all coding related to controlling. Controlling task understanding (CTU), controlling environment (CEnv), and controlling emotions (CE) each contributed an additional 4%, and controlling behavior (CB) contributed 3%. Thus, these five codes accounted for approximately 97% of all controlling codes.

Table 4.6

<table>
<thead>
<tr>
<th>Task</th>
<th>Raw count (M)</th>
<th>Controlling codes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CTP (%)</td>
</tr>
<tr>
<td>UO Group</td>
<td>48.8</td>
<td>80.7%</td>
</tr>
<tr>
<td>CO Group</td>
<td>36.2</td>
<td>84.0%</td>
</tr>
<tr>
<td>Mixed Group</td>
<td>21.4</td>
<td>85.0%</td>
</tr>
<tr>
<td>Average</td>
<td>35.5</td>
<td>82.7%</td>
</tr>
</tbody>
</table>

Note. UO = Uncertainty-oriented. CO = Certainty-oriented. CTP = Controlling task plan. CTU = Controlling task understanding. CEnv = Controlling environment. CE = Controlling emotions. CB = Controlling behavior.

In evaluations of their work (see Table 4.7), groups were once again focused on task execution, as evidenced by the top four codes: evaluating success of the plan (ESP), evaluating task progress (ETP), evaluating through social comparison (ESC), and evaluating task completion (ETC).

Table 4.7

<table>
<thead>
<tr>
<th>Group</th>
<th>Raw count (M)</th>
<th>Evaluating codes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ESP (%)</td>
</tr>
<tr>
<td>UO Group</td>
<td>7.4</td>
<td>64.9%</td>
</tr>
<tr>
<td>CO Group</td>
<td>9.8</td>
<td>42.9%</td>
</tr>
<tr>
<td>Mixed Group</td>
<td>4.4</td>
<td>45.5%</td>
</tr>
<tr>
<td>Average</td>
<td>7.2</td>
<td>50.9%</td>
</tr>
</tbody>
</table>

Note. UO = Uncertainty-oriented. CO = Certainty-oriented. ESP = Evaluate success of plan. ETP = Evaluate task progress. ETC = Evaluate task completion. ESC = Evaluate through social comparison.
**Qualitative findings.** Through Research Question 1, I investigated how collaborative groups of preservice elementary school teachers socially regulated their learning when they encountered scientific uncertainty inherent in the task. To fully answer this question, in addition to the quantitative data presented in the previous section, I used qualitative data from sociocultural discourse analysis to gain additional insight into groups’ regulation of learning and discern main themes that were common for all three groups. In the excerpts from groups’ discourse that illustrate my findings, I presented discourse markers of uncertainty in bold font. I included students’ nonverbal actions in italic font in parentheses. For the ease of understanding student dialogue, when needed, I added text in square brackets to provide additional clarifications (e.g., in Excerpt 2, *guys* referred to [straws] used in the task). Three common themes that emerged across the three groups were: collaborative approach to task completion, regulatory processing primarily focused on task, and the use of social comparison in regulation of learning.

**Collaborative approach to resolving uncertainty.** All three groups shared a collaborative approach to working on tasks and resolving encountered dilemmas. As described in the previous section, all three groups engaged in SSRL more than in the other modes of regulation, but the UO and Mixed groups engaged in it more than the CO group (see Table 4.3). However, qualitative analysis also revealed variation in the quality of groups’ SSRL, not just quantity. A qualitative review of the SSRL episodes in the UO and Mixed groups reflected equitable participation and respectful discussions (e.g., Excerpts 1–4). In contrast, even within SSRL episodes in the CO group, I found behaviors that eroded group cohesion, such as ignoring or disrespecting group members (e.g., Excerpts 5 and 6) or individual decision-making.
Excerpts 1 and 2 from the UO group dialogue exemplify the joint resolution of uncertainty that was prevalent in the group’s work.

Excerpt 1. UO group: Making an informed purchase

1 Emma: How many cotton balls could we get if we put all the rest of the budget in the cotton balls?

2 Rose: 16. I think we should see how much bubble wrap we are getting for our [money]

3 Emma: I think we need to see what this stuff looks like… (She gets up.)

4 Sarah: (Sarah gets up taking her sheet with her.) Yeah, I agree. I think we need to make an informed purchase with the rest of our money.

5 Julie: (Julie and Rose get up too, and bring along their sheets.) It’s hard to tell if things are expensive without looking at them.

In Excerpt 1 from Task 3, the group was finalizing their design for the egg drop container while staying within the $500 budget for supplies. In Turn 1, Emma attempted to clarify the group’s plan about where to invest the remainder of the budget. Rose’s suggestion (i.e., Turn 2) to see how much bubble wrap the group could get prior to deciding on cotton balls was somewhat tentative as seen through her use of the modal verb should in her statement. Emma, Sarah, and Julie’s statements (i.e., Turns 3, 4, and 5) reflected progressively more certainty as the group solidified their decision to change their course of action and take a closer look at the supplies before finalizing their design.

Excerpt 2. UO group: Is the tennis ball going to roll off?

6 Sarah: Is the tennis ball going to roll off?
7 Rose: That's why we need to create a barrier, to keep him in here. Let's use the rest of our tape to do a little line, and a little line and stack these guys [straws] up. *(She holds up a few straws next to the construction to demonstrate her idea.)*

8 Julie: Well…These guys **could probably** fit in here. *(She tries to fit in a few straws as Rose suggested, but she is not successful. Long pause.)* Or can we just adjust it so that it's a little bit more flat? *(Rose and Sarah nod in agreement).*

In Excerpt 2 from Task 4, Sarah noticed that the group’s tilted straw tower construction might not pass the test of holding the tennis ball. Rose and Julie addressed her concern by offering possible solutions to this problem. Rose suggested adding barriers to the existing construction to prevent the ball from rolling (see Turn 7). In Turn 8, Julie resolved the uncertainty around how feasible Rose’s idea might be by attempting to fit the additional straws into the construction. When Julie was unable to fit the straws, she suggested flattening the platform of the existing construction to eliminate the tilt. The other two students accepted her suggestion. This example is one more illustration of how the group jointly resolved the design problem by working through the members’ dilemmas and suggestions to choose the best course of action.

Mixed group’s interactions during their SSRL were similar to the previously described UO group’s interactions. Excerpts 3 and 4 respectively illustrate the Mixed group’s joint planning of their parachute and egg container designs.
Excerpt 3. Mixed group: What if the coffee filter was our parachute?

9    Kate: I mean, what if the…Oh, no, that **would**… There's coffee filters over there. What if the coffee filter was our parachute, and then we just had four strings? Like, we recreated everything else except…

10   Stella: With a coffee filter.

11   Kate: …With a coffee filter.

12   Stella: Or added vents so the air **could** go through.

13   Kate: True. *(Kate goes to get the coffee filter.)*

14   Tom: The coffee filter **may** even help with that because it's more porous than a plastic sheet already. *(Jane gets up and starts examining their original parachute.)*

15   Stella: It **should** hold the shape better…plus it’s lighter.

In Excerpt 3, from Task 2, Kate proposed using a coffee filter (i.e., Turn 9) as a design change aimed at slowing down the parachute fall. In Turn 12, Stella suggested an alternative (i.e., adding vents to the existing plastic sheet), but after Tom offered a supporting reason for why a coffee filter would be a good choice (see Turn 14), she added an additional reason in favor of choosing a coffee filter design (see Turn 15). Similarly, in Excerpt 4, the Mixed group planned an egg container design that would enable them to protect the egg from breaking while adhering to the $500 budget.

Excerpt 4. Mixed group: A plastic bag is required

16   Kate: If a plastic bag's only $50 I think we **should** do a parachute. That **would** be easy. Plastic cups, God damn. $150?

17   Tom: *(Points to the instructions.)* And a plastic bag is required.
In Turn 16, Kate suggested adding a parachute (i.e., a plastic bag) to their design without realizing that one of the task requirements dictated they place the container into a Ziplock bag. The group then jointly modified their understanding of the task requirement (Turns 17–23). Based on this new understanding, they decided to forego the use of the parachute in their design. Excerpts 1 through 4 illustrate the UO and the Mixed groups’ collaborative approach to resolving uncertainty, characterized by SSRL enacted through equitable participation of multiple group members and respectful statements that build on each other toward a joint solution.

In contrast, the CO group often dismissed their members’ concerns with only superficial comments or by diverting attention to another aspect of the task. Small but persistent acts of disrespect characterized their collaborative engagements and eroded group cohesion. Excerpts 5 and 6 from the CO group illustrate these findings. I coded these excerpts as SSRL because the group members’ statements were followed by uptake and contributions from others and are in service of joint regulation of group’s learning. However, SSRL enacted in this fashion is qualitatively different than SSRL enacted by the other two groups (e.g., Excerpts 2 and 3).

Excerpt 5. The CO group: We gotta do the average.

24 Kerry: I hope I'm holding it at the same height every time. (She laughs.)

25 Parker: It's fine.
26  Kerry:  Ready? Go.

27  Alice:  Ooh, that was a quick one. *(Laura, Alice, and Parker write on their sheets. Kerry steps down from the chair and sits down.)*

28  Kerry:  Maybe that time it was kind of circled around itself. The strings were kind of twisted. Maybe that made a difference because it was kind of like this.

29  Laura:  Do you have a calculator? We gotta do the average.

In Excerpt 5 from Task 2, the CO group dropped their parachute in the last of three trials and recorded the time it took to fall. In turn 24, Kerry expressed uncertainty about the drop height being constant. Parker quickly reassured her that “it’s fine” without offering any additional evidence (e.g., a comparison to a reference point in the classroom). In Turn 28, Kerry noticed an irregularity in the last trial when the parachute strings were twisted. Kerry expressed uncertainty about the reasons for the parachute speed change and thus, implicitly, about the validity of that trial, but other group members ignored it. Instead of addressing the uncertainty in some way, Laura prompted the group to press on and calculate the average.

In Excerpt 6 from Task 3, the group finished building their egg drop container (i.e., the plastic cup filled with protective materials surrounding the egg). The group members stood around the table in the following order from left to right: Laura, Alice, Parker, and Kerry. Kerry invited others to check the plastic cup with the egg and protective materials.

*Excerpt 6. CO group: I think it’s fine.*

30  Kerry:  Okay. Pass it around, feel it. *(Kerry puts the cup on the table in front of Parker who is yawning.)*
Parker:  *(Parker briefly touches the top of the cotton balls in the cup.)* It's good. *(Laura extends her hand towards Parker, who gives her the cup, bypassing Alice who is standing between them.)*

Alice:  I wish we filled it up though, **I don't know**… I just don't feel good that it's not filled up.

Laura:  *(Touches the top of the cotton balls in the cup.)* I think it's fine.

In Turn 31, Parker checked the cup and passed it directly to Laura. Both Laura and Parker ignored and bypassed Alice, who should have been the next group member to inspect the group’s work product. Alice did not verbally react to this disrespectful act, but in Turn 32, she expressed doubt about the group’s design. Similar to the quick dismissal of the group members’ concern from Excerpt 5, Laura provided her assessment of the cup filling (Turn 33) as the conclusion to the group’s inspection of the cup.

Secondary sources (i.e., blog posts and participants’ responses to pre-task questions) offered additional support for the finding that all three groups shared collaborative approaches to working on tasks. Emma, from the UO group, wrote in her blog post about the escape room: “I liked getting to work as a team—it really highlighted our strengths to each other. Some kept us on task, some read closely, some solved the more technical clues.” In her blog post reflecting on the card sort activity and the pooling of knowledge in the small groups, Alice from the CO group wrote: “So I was a bit lost in this activity and really had to rely on my teammates.” Tom, from the Mixed group, wrote in his escape room blog post: “A lot of work and creativity goes into making an escape room successful, and I enjoy the collaboration and teamwork that goes into solving puzzles.” Emma and Tom’s reflections were well aligned with the observed positive and collaborative nature of their groups’ engagement. However, Alice’s reflection was not inclusive.
of the negative aspects of the observed CO group dynamic, but rather, she self-reported the positive aspect of it (i.e., her reliance on her teammates).

In their pre-task responses, students often mentioned feeling confident about task completion even if they personally did not fully understand the task or have ideas about how to start because they were working collaboratively and could rely on team members. For example, in her response prior to Task 4, Rose, from the UO group, stated that she felt fairly confident and specified: “I don’t have a lot of ideas right off the bat but I feel confident that my group members will work with me and we can all come up with great ideas to get the task completed.” Parker, from the CO group, wrote in her response prior to Task 2: “I also know that my group members will help me in areas where I don’t understand.” In her response to the question prior to Task 3, Kate, from the Mixed group, shared that she was not 100% sure what they were going to do, but then stated: “I think w/ the help of my group members we will be able to get it done.”

This finding aligns with findings from Huber et al. (1992), in which both the UO and the CO participants preferred collaborative learning over individual study and competitive learning situations, but the UO participants preferred collaborative learning significantly more than the CO participants. Huber and colleagues investigated reactions of certainty- and uncertainty-oriented preservice teachers to engagement in collaborative learning and found differences between UO and CO participants. Similar to Alice and Parker’s focus on only positive aspects of their group’s engagement, Huber et al. found when asked about interactions within the group, CO participants reported there was no need to engage in reaching group consensus, thus denying any disagreements within the group. On the other hand, they also reported not agreeing with their groups’ opinions. Conversely, the UO participants reported various ways in which their group worked together to reach consensus, and appraised their groups as more positive and task-
oriented than the CO participants. This finding indicates that the quality of the CO group’s social regulation of learning might have suffered because the group members chose to deny and ignore the dissonance or disagreements within the group rather than address them directly.

To summarize, I found that all three groups engaged in collaborative work with SSRL as the most dominant mode of social regulation of learning, but the nature of collaborative work varied between the UO and Mixed group, and the CO group. The UO and the Mixed groups’ SSRL was characterized by respectful and equitable interactions. In contrast, CO group engaged in SSRL of lower quality, with many instances of disrespect and quick dismissals of group members’ concerns.

*Regulatory processing primarily focused on task.* As previously discussed in the section on frequencies of regulative processes and targets, when regulating, all three groups across all five tasks focused on monitoring and controlling some aspect of the task, rather than focusing on regulation of the content learning (e.g., content planning, monitoring of content understanding, and evaluating content understanding). Qualitative analysis confirmed these findings. Excerpts 1–6 illustrated students’ primary focus on task regulation, which was evident among all of the regulation episodes. The few turns in which students focused on regulating content (i.e., Episode 3, Tom in Turn 14 and Stella in Turn 15; Episode 5, Kerry in Turn 28) were fleeting and in service of task progress. In Episode 3, Tom and Stella used their understanding of parachutes to judge the coffee filter to be a good choice of the material based on porosity, shape, and weight. In Episode 5, Kerry monitored the fit between her understanding of a valid parachute drop trial and the trial she executed and found potential discrepancies as reflected in her use of uncertainty discourse markers *maybe* and *kind of.*
Students were aware that their focus on task completion detracted from the regulation of content learning, as evidenced in their blog posts about the escape room task. Sarah from the UO group wrote: “I think possibly more scaffolding would have helped us work through the box while actually absorbing the key content that was being presented as well.” In the CO group, Kerry’s blog post included the following observation: “It is hard to pay attention to learning about composting when I feel like I am just trying to solve the puzzle as quickly as possible.” In his blog about the escape room, Tom, from the Mixed group, stated: “The only thing I could say is that there is a huge possibility of getting lost in the puzzle aspect of trying to figure things out without really focusing on the knowledge you could gain from the experience.” It is important to say that students’ content learning was beyond the scope of this study, which included no measures of students’ content knowledge. Thus, the finding about the primary focus of students’ regulatory processing on aspects of task and not content is a reflection on regulative processing and not on the changes in students’ content learning, which may happen without engaging in regulative processes.

**Use of social comparison in regulation of learning.** During the coding of regulative processes and targets, both coders independently recognized the need to introduce new inductive codes for the use of social comparison in regulation of learning. *Social comparison* refers to people’s tendency to benchmark themselves against others and is one of the drivers of competitive behavior (Garcia, Tor, & Schiff, 2013). Thus, we added new codes for monitoring through social comparison, controlling through social comparison, and evaluating for social comparison. Qualitative analysis of the transcripts helped contextualize this phenomenon. In science classrooms, group work is done simultaneously and publicly, affording collaborative groups opportunities to inconspicuously or quite openly compare themselves to others. Based on
the comparisons, groups were able to gauge their own progress, reconsider their plans, and either maintain or change the course of action if they judged it to be ineffective. In my study, all three groups occasionally compared their group to other groups to monitor task plan or task progress or to judge their work products and task outcomes. In Excerpts 7 and 8 from Task 3, the UO group and the Mixed group noticed other groups inflated their bags with air, but the two groups took different actions.

*Excerpt 7. UO group: Let's copy.*

34 Sarah: *(Whispering)* Okay guys, they inflated their bags. *(Emma, Julie, and Rose look over to the other groups.)*

35 Emma: Oh, that's really smart. Let's copy.

36 Julie: What if it pops?

37 Sarah: We have a parachute though.

38 Julie: Yeah, we do have a parachute.

39 Emma: But then our parachute is attached to the bag. Right? *(Emma is continuing to work on poking one more hole in the cup.)*

40 Rose: Don't you think if it's inflated though, when it drops, it *might* cause it to tip over.

41 Emma: And, in the bag, it *might* move around. *(Gestures with her hands in a circular motion)*

In Excerpt 7, Sarah noticed that all other groups were inflating their bags with air for the egg drop experiment. In Turn 35, Emma judged that approach to be smart and suggested they should do the same. The UO group members then discussed the positive aspects of their own plan (Turns 37 and 38) that included a parachute and the potential shortcomings of inflating the
bag with air (Turns 36, 40, and 41) and decided to stick with their own design. In this case, monitoring through social comparison (Turns 34 and 35) led the group to reconsider their plan and reason through options. The UO group decided to stay with their original plan and were the only group not to inflate their bag with air. In Excerpt 8, the Mixed group had just finished building their container when they decided to make a change and inflate the bag based on what they saw the other group do.

*Excerpt 8. Mixed group: Should we blow it up with air like they did?*

42 Tom: All right. *(Tom holds up group’s Ziploc bag with the egg wrapped up in protective materials.)*

43 Stella: All right.

44 Jane: Nice. Wait, **should** we blow it up with air-

45 Stella: Yeah, **definitely**. *(Tom unzips the bag and starts adjusting its contents to capture more air.)*

46 Jane: …like they did. Do like a small little…like even…*(Tom closes the bag trapping some air inside, but not enough to create an air pillow.)*

47 Stella: Can I try? I’ll do it. Oh, you got it?

48 Jane: *(Passes the bag to Stella) … Like blow in …*

49 Stella: Yeah. We're really going to… I think it's going to balance. *(Tom laughs. Stella blows air into the bag.)*

50 Jane: Okay, I'm hopeful. It's like a pillow. Oh my gosh.

51 Tom: It's like a pillow. *(Jane picks up the bag and gently drops it on the table.)*

52 Stella: Oh yeah!
Jane: I think we got it. *All three students laugh and nod.*

The Mixed group did not discuss the change Jane suggested (Turn 44) but embraced it immediately (Turn 45) and adapted their plan (Turns 46 and 49). In other cases, as shown in Excerpts 9 and 10, monitoring of task progress through social comparison enabled groups to benchmark their task progress, providing some reassurance they were on the right track.

*Excerpt 9. CO group: We're ahead of everyone else.*

Kerry: *(Looks around the classroom)* It seems like we're ahead of everyone else.

Alice: I don't think so. They're all on the same page.

Kerry: People are just starting.

In Excerpt 9, from Task 5, the CO group engaged in monitoring through social comparison as the group became a bit frustrated with a time-consuming card game, which was part of an escape room puzzle. In Turn 54, Kerry pointed out that they were ahead on the task. When Alice contradicted her in turn 55, Kerry provided a more specific evaluation (i.e., Turn 56) of the other groups’ progress stating that “people are just starting,” thus reassuring the group that they were truly ahead of the others. Then the group continued to play the card game until they finished it.

*Excerpt 10. Mixed group: Other people don't have theirs on either.*

Stella: *(Reads.)* Part A will go on top. Okay. Then, our stuff goes in it.

Kate: Oh, nice. Somehow. *(Tom is trying to fit the top part into the bottom part of the bioreactor.)*

Stella: Maybe we just tape it or something.

Tom: Do we have to clip it?
Kate: Do we like rubber band? Or, no.

Stella: Yeah, *probably*.

Kate: *Maybe?*

Stella: It [the instructions sheet] doesn't say, but other people don't have theirs on, either.

Kate: *Could* we cut like a slit to just make it fit over? Or, no, that *might*... Or, *would* it be easier to slip it in?

Tom: Like, inside of it?

Stella: All the way inside of it?

Kate: Yeah.

Similarly, in Excerpt 10 from Task 1, the Mixed group tried to figure out how to attach Part A of their bioreactor to the rest of the container. The group members offered three different ways of doing it (Turns 59–61) but were not sure how to proceed. Stella’s observation (i.e., Turn 64) that the other groups also had not figured it out yet reassured the group that they were not worse off than the others and led them to continue their discussion. Kate suggested a new way to fit the two parts of the bioreactor together (i.e., Turn 65), which is what the group ended up doing.

Excerpt 11 is an example of the CO group retrospectively evaluating their work product (i.e., the straw tower) against the design implemented by another group. Although this part of the student dialogue does not include uncertainty markers, I believe it contributes to a more complete portrayal of the regulation of learning that took place in the observed groups because it provides additional information about ways in which groups self-evaluate through social comparison.
Excerpt 11. The CO group. Ours is the discount version of theirs.

69 Alice:  Theirs is nice.

70 Parker:  Theirs is like ours but better.

71 Kerry:  Yeah. Ours is the discount version of theirs.

72 Alice:  But it works. If it works, doesn't matter.

73 Laura:  Everyone wants cheaper. (All students smile.)

Excerpt 11 happened at the end of Task 4, which was a particularly trying task for the CO group due to the negative group climate. Parker and Kerry (i.e., Turns 70 and 71) offered negative views of the group’s tower. Alice and Laura (i.e., Turns 72 and 73) pointed out good aspects of the group’s design (i.e., it works and it is cheaper), thus orienting the group towards the positive outcome of their sometimes testy collaboration.

Additionally, I found elements of social comparison in the science biography blogs of the CO group members, but not in the blogs written by members of the other two groups. The CO group members reflected on their science experiences in school and recalled feelings of inadequacy as they compared themselves to others. Alice wrote: “I do remember taking science-specific courses throughout high school. First, there was chemistry, then biology, and lastly, environmental science. None of them appealed to me. If some people soared through these classes, I trudged.” Similarly, Kerry wrote about fearing not being on par with other students in the science fair: “I remember being very frustrated with the science fair because I was scared mine would not be good enough. It becomes too competitive.” Laura’s reflection from her science autobiography blog post involved a memory of a failed fifth-grade science test:

At the end of my 5th grade year, I failed my science end of grade test. It was really embarrassing because all of my friends had passed and I had to remediate the class and retake the test while everyone else got to enjoy the last few days of school watching
movies and having extended recess. Starting then, science became my least favorite subject.

Thus, social comparison plays a role in shaping students’ science learning experiences and in their regulation of learning in science.

**Summary for Research Question 1.** With Research Question 1, I investigated how collaborative groups of preservice elementary school teachers socially regulated their learning when they faced scientific uncertainty inherent in a task. I found the following three themes that were similar across all three groups: collaborative approach to task completion, regulatory processing primarily focused on task, and use of social comparison in regulation of learning. All three groups worked collaboratively to resolve the uncertainties encountered during their task engagement. However, there were differences across groups in frequencies of groups’ SSRL, as well as differences in the quality of their collaboration, which were reflected in the quality of groups’ SSRL. I found that the CO group had a lower percentage of SSRL (i.e., 39%) than the UO (i.e., 56%) and Mixed (i.e., 58%) groups. Likewise, I found lower quality SSRL in the CO group than in the UO and the Mixed groups. All three groups focused their regulative processing primarily on the various aspects of the task and engaged little in the regulation of learning of the relevant subject matter content. In their regulation of learning, groups used social comparison with the other groups in the class to monitor and control their own task plans and progress and to judge their work products. These overall trends in groups’ enactment of social regulation of learning are important because they characterized similarities in groups’ general approach to the social regulation of learning as they grappled with uncertainty in the series of science tasks.

Next, I examine how the enactment of social regulation of learning varied with respect to each group’s uncertainty orientation and the degree of situational uncertainty in the task.
Findings for Research Question 2

Research Question 2: How does preservice teachers' enactment of social regulation of learning during collaborative inquiry vary with respect to the degree of situational uncertainty in the task and the uncertainty orientation of the group?

To answer this research question, I included data representations that are most helpful for illustrating the observed differences between groups and across tasks. I followed the presentation of quantitative data with qualitative analysis to describe the specific interactions representative of the ways in which the groups regulated their learning. Where it was helpful to describe group dynamics that unfolded through the series of five tasks, I also included data for the baseline task. As a reminder, the baseline task was a simple 10-min, collaborative card-sorting activity that relied on students’ content knowledge of different ways to dispose of waste (i.e., reuse, compost, recycle, discard) and preceded the five inquiry tasks. Then, the five-task series was bracketed on either end by a high-uncertainty task: Task 1 (i.e., building of the bioreactor) and Task 5 (i.e., solving an escape room). Task 2, the parachute inquiry, was the lowest uncertainty task in the series. Tasks 3, the egg drop experiment, and Task 4, the building of a straw tower, were both medium-uncertainty tasks, but, as described in Chapter 3, Task 4 included four types of scientific uncertainty, whereas Task 3 included three types of scientific uncertainty. Thus, it was reasonable to expect that students would perceive Task 4 as more complex or difficult. Time needed to complete each task varied, so in the following section I give an in-depth examination of task times and differences in the groups’ on- and off-task engagement.

Differences in on- and off-task engagement. Duration of the on-task engagement varied by task and group (Table 4.8). Whereas the instructor limited the duration of the baseline activity
to approximately 10 min, the other tasks did not have a preset, firm end-point. Rather, a task’s
duration was determined by how long it took the groups to complete it.

Table 4.8

<table>
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<tr>
<th></th>
<th>Baseline</th>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Task 4</th>
<th>Task 5</th>
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<td>19</td>
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</table>

After the baseline activity, the average on-task time increased for Task 1, the high-
uncertainty task. Groups spent the least amount of time on Task 2, which was the low-
uncertainty task (Figure 4.2). After Task 2, as the level of uncertainty increased for Tasks 3, 4,
and 5, so did the groups’ average on-task time. Average off-task time also increased slightly
from the baseline, leveling off for Task 3 and 4. Interestingly, Task 5 was characterized by the
absence of off-task conversations.
Analysis of on- and off-task engagement across the series of five tasks by group showed that of the three groups, the UO group spent the most time on task and the least time off-task (Figure 4.3). On average, the UO group spent approximately nine minutes more on-task than the CO group, and around six minutes more than the Mixed group. In contrast, the CO group spent less time on-task and engaged in more off-task conversations than the other two groups.

I present on- and off-task time for each task by group in Figure 4.4. Of the three groups, the UO group spent the most and the CO group the least time on-task in every task, with the exception of Task 5 when the Mixed group spent the least amount of time on-task because they were the first to complete the escape room. Interestingly, the CO group’s off-task time increased steadily through Task 4 before dropping to zero in Task 5.

*Figure 4.2. Average time by task spent on- and off-task.*
Qualitative analysis revealed that the UO group’s longer on-task engagement arose from the group’s pursuit of creative task solutions, which generally took more time to execute (e.g., use of a parachute in the egg drop experiment in Task 3, hammock-like design in Task 4), as well as the group’s tendency to continue working during reporting out or after most other groups were finished. The CO group’s off-task engagement, which increased as the uncertainty of the tasks increased and culminated in Task 4, was likely due to the withdrawals of group members from the task, which I explain further in the qualitative analysis section.
Based on uncertainty orientation theory (Huber et al., 1992), I posit that the increase in percentage of off-task time from Task 1 to Task 4 for the CO group might have been their way of coping with the discomfort caused by the lack of task structure in Tasks 1–4. These tasks were characterized by the possibility of multiple solutions. The sequential structure of the escape room, in contrast, provided only one possible path for advancing through the task, and each puzzle lock had only one correct code that unlocked it. Hence, the existence of firmer structure and only one right solution for each puzzle might have helped the CO group members refocus their collaborative efforts in Task 5. Consistent with uncertainty orientation theory (Sorrentino & Roney, 2000), members of the UO group were the least driven to engage in Task 2, the low-uncertainty task, and showed a greater percentage of on-time engagement in the other four tasks that were characterized by higher levels of uncertainty. I made no inferences about how the task uncertainty levels might have shaped the observed fluctuation in percentages of on- and off-task behavior for the Mixed group because, according to uncertainty orientation theory, the behavior of moderates cannot be predicted (Sorrentino & Roney, 2000).

**Differences in group dynamics.** To fully understand the differences among groups, it is important to consider each groups’ socio-emotional (SE) interactions and climate. As a reminder, SE climate is defined as a stable pattern of group members’ shared SE interactions, emotions, and behaviors observed over multiple collaborative sessions (Bakhtiar et al., 2017). The coders utilized a total of 12 SE codes, six for positive, and six for negative SE interactions. A closer look at the SE coding revealed that all three groups engaged in positive interactions (Figure 4.5), with the UO group engaging in them the most and the CO group the least. However, the main difference among the groups seemed to be the number of negative SE interactions the CO group engaged in as compared to the number of negative SE interactions in the UO and Mixed groups.
Moreover, the CO group’s normalized counts revealed that their negative SE interactions outweighed their positive interactions.

![Figure 4.5. Socio-emotional (SE) interactions: Average raw and normalized frequency count across five tasks.](image)

Next, I considered how groups’ SE interactions unfolded across the tasks. Starting with the baseline task, there was a noticeable difference in the SE interactions among groups, ultimately leading to differences in each group’s observed SE climate (see Figures 4.6 and 4.7). The UO group and the Mixed group started with positive SE interactions in the baseline task and Task 1, and developed and sustained a positive SE climate. The CO group had fewer positive SE interactions than the other two groups in the baseline and Task 1. Although the number of their positive interactions increased in the later tasks, the CO group’s persistent negative SE interactions outweighed their positive interactions, forming a negative SE climate. Whereas the UO and the Mixed groups had almost no negative SE interactions across the series of tasks, negative SE interactions in the CO group were numerous and formed a U-shape pattern from baseline task to Task 4. Namely, the CO group started off with negative interactions during the baseline task. Then, their negative interactions decreased in Tasks 1 and 2 but later increased and
worsened as the semester progressed and the task uncertainty level increased, culminating in Task 4. In Task 5, members of the CO group had their lowest number of negative interactions.

**Figure 4.6.** Positive socio-emotional (SE) interactions: Raw and normalized frequency counts.

**Figure 4.7.** Negative socio-emotional (SE) interactions: Raw and normalized frequency counts.

To discern the details of the groups’ positive and negative SE interactions, I focused on the most prominent positive and negative SE codes. The two most prominent codes for positive SE interactions were respect and active listening (SE+ R/AL) and fostering group cohesion (SE+ FGC), which together accounted for approximately 90% of all positive SE interactions. As previously mentioned, all three groups engaged in positive SE interactions. However, the UO
group accounted for approximately 44%, the Mixed group for approximately 30%, and the CO group for approximately 26% of the instances of SE+ R/AL and FGC codes. Through the examination of the two most prominent codes for negative SE interactions, (i.e., low group cohesion [SE- LGC], and disrespect [SE- DIS]), which combined accounted for approximately 93% of all codes for negative SE interactions, I found the CO group accounted for approximately 81% of all low group cohesion codes and for 90% of all codes for disrespect (Table 4.9).

Table 4.9

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Codes for instances of disrespect were especially important for understanding the group dynamics. Whereas the UO and the Mixed groups each had just one instance of disrespect occurring over the span of five tasks, the CO group had 18. Instances of disrespect for the CO
group culminated in Task 3, with nine occurrences, most gratuitously directed at the same group member (i.e., Alice). The CO group’s SE climate worsened in Task 4, with five occurrences of the code for targeted ignoring and rejection (i.e., SE-TIR). Qualitative analysis showed that, in Task 4, the group rejected one of their members (i.e., Kerry) for several minutes following an incident during which Kerry dropped a handful of straws without cause into the construction the other students had built. The excerpt including this incident is included in the section on qualitative findings (Excerpt 27). The other two groups had no occurrences of the SE-TIR code.

Interestingly, after this SE implosion in Task 4, the CO group looked much more like the other two groups in Task 5 (i.e., lower number of SE-codes). My finding that the CO group had their lowest combined number of instances of the low group cohesion and disrespect codes in Task 2 (i.e., the low-uncertainty task) and in Task 5 (i.e., the task characterized by sequential structure) aligns with findings from Huber (2003), who found that differences in decision-making between the UO and CO groups diminished in well-structured tasks. Building on Huber’s findings, I speculate that clear and firm structure of the escape room somewhat moderated the uncertainty level and helped the CO group to stabilize and engage on more equal footing.

Regulative episodes and modes of regulation. As I presented in findings for Research Question 1, the UO and CO groups each had an average of 17 regulative episodes per task, and the Mixed group had 12 regulative episodes (Table 4.2). The groups differed in how much they relied on each particular mode of regulation of learning. For all three groups, SSRL was the most prevalent mode of regulation. However, only 39% of the CO group’s modes of regulation were attributed to SSRL versus 58% in the Mixed group and 56% in the UO group. The CO group members relied on their individual regulation of learning (i.e., SRL) more than the members of
the other two groups (see Table 4.3); SRL accounted for approximately 33% of the CO group’s identified modes of regulation. In contrast, SRL accounted for approximately 11% of the identified modes of regulation in the UO group and approximately 5% in the Mixed group. An important difference, which I show through qualitative findings, was that in the UO and Mixed groups, group members’ SRL statements expressing some type of dissonance (e.g., Emma’s statement “I don’t know about those,” Excerpt 19, line 138) typically prompted coRL or SSRL modes of regulation. In the CO group, group members typically did not respond to the others’ SRL statements (e.g., “I don’t know how to make it slower,” Excerpt 25, line 182), thus resulting in a higher percentage of SRL as well as low group cohesion and negative SE climate. Typically, group members’ responses to each other’s SRL statements create opportunities for the group to advance towards achievement of their goals either by joint regulation through SSRL or, if needed, by providing temporary guidance to one or more group members through coRL. Absence of a response to a group member’s SRL statements (i.e., ignoring and rejection) precludes group from engaging in SSRL or coRL, and further erodes the group’s cohesion and perpetuates the cycle of negative SE interactions (Rogat & Linnenbrink-Garcia, 2011, 2013).

Review of regulative episodes by task showed the average number of regulative episodes decreased from 14.7 in Task 1 (Table 4.10), a high-uncertainty task, to 11 episodes in Task 2, a low-uncertainty task. Then, the average number of regulative episodes rose to 17.3 episodes in Tasks 3 and 4, which were medium-uncertainty tasks, and declined to 15.3 in Task 5, a high-uncertainty task. These trends about the number of regulative episodes seem to suggest that the low-uncertainty task, Task 2, necessitated less engagement in regulation of learning than tasks of higher uncertainty. SSRL was the most prevalent social mode of regulation in each task, followed by coRL and SRL. However, in two high-uncertainty tasks, Task 1 and 5, groups relied
on external regulation episodes more than on coRL or SRL. The higher percentage of episodes attributed to the external regulation of learning indicates that groups’ reliance on the instructor’s help was more pronounced in the two high-uncertainty tasks than in others, resulting in external regulation being identified as a dominant mode of regulation for those episodes. Of the five tasks, the lowest percentage of external regulation episodes occurred in Task 2, the low-uncertainty task. Inferences about trends in these data should be tempered by findings presented next, where I discuss how including data beyond dominant modes of regulation reveals a more complete picture of the regulation of learning in the groups.

Table 4.10

<table>
<thead>
<tr>
<th>Task</th>
<th>Number of episodes (M)</th>
<th>Social mode of regulation</th>
<th>External regulation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>SSRL (%)</td>
<td>coRL (%)</td>
</tr>
<tr>
<td>Task 1</td>
<td>14.7</td>
<td>68.2%</td>
<td>9.1%</td>
</tr>
<tr>
<td>Task 2</td>
<td>11.0</td>
<td>75.8%</td>
<td>9.1%</td>
</tr>
<tr>
<td>Task 3</td>
<td>17.3</td>
<td>75.0%</td>
<td>13.5%</td>
</tr>
<tr>
<td>Task 4</td>
<td>17.3</td>
<td>76.9%</td>
<td>11.5%</td>
</tr>
<tr>
<td>Task 5</td>
<td>15.3</td>
<td>71.7%</td>
<td>8.7%</td>
</tr>
<tr>
<td>Average</td>
<td>15.1</td>
<td>73.6%</td>
<td>10.6%</td>
</tr>
</tbody>
</table>


A look beyond dominant modes of regulation for episodes and a closer examination of the overall frequency counts for each mode of regulation (Table 4.11) showed that a greater portion of SRL and external regulation occurred during group members’ regulation of learning in each of the five tasks than could be gleaned from the data about dominant modes of regulation (Table 4.10). In Tasks 1 and 2, the combination of SRL and external modes of regulation accounted for approximately 41% of all identified occurrences of various modes of regulation in each task. In Tasks 3 and 4, the portion of SRL and external regulation decreased slightly to
approximately 39% and then sharply increased to approximately 49% in Task 5, primarily driven by the greater number of occurrences of individual regulation of learning (i.e., SRL).

Table 4.11

### Frequency of Modes of Regulation Across Tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>Count (M)</th>
<th>SSRL (%)</th>
<th>coRL (%)</th>
<th>SRL (%)</th>
<th>External regulation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>20.3</td>
<td>50.8%</td>
<td>8.2%</td>
<td>19.7%</td>
<td>21.3%</td>
</tr>
<tr>
<td>Task 2</td>
<td>16.3</td>
<td>51.0%</td>
<td>8.2%</td>
<td>16.3%</td>
<td>24.5%</td>
</tr>
<tr>
<td>Task 3</td>
<td>26.3</td>
<td>49.4%</td>
<td>11.4%</td>
<td>6.3%</td>
<td>32.9%</td>
</tr>
<tr>
<td>Task 4</td>
<td>27.7</td>
<td>50.6%</td>
<td>10.8%</td>
<td>20.5%</td>
<td>18.1%</td>
</tr>
<tr>
<td>Task 5</td>
<td>26.0</td>
<td>46.2%</td>
<td>5.1%</td>
<td>29.5%</td>
<td>19.2%</td>
</tr>
<tr>
<td>Average</td>
<td>23.3</td>
<td>49.4%</td>
<td>8.9%</td>
<td>18.6%</td>
<td>23.1%</td>
</tr>
</tbody>
</table>


Additional scrutiny of the modes of regulation by task per group (Figure 4.8) revealed that the CO group accounted for the majority of SRL occurrences in each of the five tasks: approximately 58% in Task 1, 75% in Task 2, 60% in Task 3, 88% in Task 4, and 70% in Task 5. This exploration of regulative modes by task per group illuminated a stable pattern of greater reliance on SRL in the CO group across the five tasks than in the UO and Mixed groups. Whereas the members of the UO and Mixed groups navigated through the encountered uncertainty in tasks together by engaging in SSRL and coRL, the CO group members had to significantly rely on their individual regulation of learning. As I discuss further in the next section, even after I accounted for the fact that the normalized frequencies showed the CO group regulated more than the other two groups, there was still a difference in the regulation distribution within each task.
Regulative processes and targets. In this section, first I describe differences in regulative macro-processes observed for each group and then differences observed across tasks. Then I take a deeper look at how regulative processing differed by group by task. Next, I describe the targets of the groups’ regulation (i.e., what they regulated) and changes in targets of regulation across the series of five tasks. Finally, I describe how regulative targets varied by group by task.

Regulative macro-processes. Groups differed in how much they engaged in each of the four regulative macro-processes (i.e., planning, monitoring, controlling, and evaluating). This was not unexpected. Because the groups’ cognitive conditions (e.g., uncertainty orientations, domain knowledge, motivational factors, beliefs; Winne & Hadwin, 1998) differed, I anticipated
that their initial task perceptions, as well as the subsequent regulation of learning, would be different.

According to the 4-phase COPES model of SRL (Winne & Hadwin, 1998), students generate initial task perceptions and definitions in Phase 1 and develop their plans and set strategies for realizing them in Phase 2. I found that of the three groups, participants in the UO group engaged in planning the least; planning accounted for only about 9% of all their regulation codes (Table 4.4). The Mixed group planned the most, with approximately 16% of their regulation dedicated to planning. The CO group dedicated about 12% of their regulative efforts to planning.

Monitoring was the regulative macro-process all three groups used the most, with the UO and Mixed group devoting approximately 70% of their regulation to monitoring, and the CO group approximately 67%. According to Winne and Hadwin (1998), students engage in monitoring in each of the phases of the learning process, so it was logical that it accounted for a high percentage of the groups’ regulative macro-processes. Monitoring might act as a trigger for controlling when learners detect a mismatch between the monitoring target and a standard against which they monitored it. Controlling, which refers to the adaptations learners make based on monitoring, differed across groups. Controlling accounted for about 18% of the UO group’s regulation, about 16% of the CO group’s regulation, and 11% of the Mixed group’s regulation. This finding points to the UO and CO groups having a greater need than the Mixed group to finetune their actions to achieve their goals and fulfill their plans.

As previously mentioned, of the four macro-processes, evaluating was enacted the least by all groups. This finding is consistent with other studies that showed that collaborative groups rarely engage in retrospective evaluations of their work (e.g., De Backer et al., 2015). The CO
group engaged in evaluating more than the other two groups (Table 4.4). The CO group dedicated approximately 4% of their regulation to evaluating, the UO group approximately 3%, and the Mixed group approximately 2%. My qualitative analysis showed the CO group’s focus on winning might have contributed to the group’s higher engagement in evaluating than observed for the other two groups. The Mixed group engaged in controlling (i.e., 11%) and evaluating (i.e., 2%) the least of the three groups. I return to the findings about the Mixed group’s controlling and evaluating in the qualitative analysis and further discuss findings about group differences in regulative processing in Chapter 5.

Next, I consider how regulative macro-processes differed through the series of five tasks of different uncertainty levels and highlight the most interesting findings (see Table 4.12). Although Task 1, the high-uncertainty bioreactor build task, had the highest percentage of planning codes (i.e., 25.8%), it had the lowest percentage of codes assigned to monitoring (i.e., 56.6%). This meant that in Task 1, after setting their initial plans, groups did not engage in monitoring of various targets against standards that would help them judge their progress towards their goals as much as they did in other tasks. A unique characteristic of Task 1 was that the uncertainty of the final outcome (i.e., whether the bioreactor ingredients decompose or not) was not going to be resolved in the immediate future because it took weeks for the materials in the bioreactor to decompose. I speculate that in an ill-structured task, such as Task 1, in which the final outcomes are delayed, the standards against which to monitor are not easily discernible. In turn, absence of easily accessible standards resulted in less monitoring than in other tasks. In other words, after the groups assembled their soda bottles into bioreactor containers, it was difficult for them to know what criteria to use to further evaluate their bioreactors, and the
inaccessibility of the criteria was reflected in the lower percentage of monitoring in this task than
in others. Percentage of codes assigned to planning declined steadily from Task 1 to Task 5.

Task 2, the low-uncertainty task, had the least percentage of codes assigned to
controlling, only 8%. This finding indicates that in a low-uncertainty task, once they set their
plans, groups had less need to alter their course of action than in the tasks of higher uncertainty
levels. In Tasks 3, 4, and 5, controlling was more prominent than planning. Task 4, the slightly
more difficult of the two medium-uncertainty tasks, had the highest percentage of controlling
(i.e., 20.1%) and evaluating (i.e., 5.6%) codes. Thus, for ill-structured tasks, as the uncertainty
level increased, groups engaged in more adaptations of their actions.

Table 4.12

<table>
<thead>
<tr>
<th>Task</th>
<th>Count (M)</th>
<th>Planning (%)</th>
<th>Monitoring (%)</th>
<th>Controlling (%)</th>
<th>Evaluating (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task 1</td>
<td>121.3</td>
<td>25.8%</td>
<td>56.6%</td>
<td>12.6%</td>
<td>4.9%</td>
</tr>
<tr>
<td>Task 2</td>
<td>112.3</td>
<td>22.8%</td>
<td>65.0%</td>
<td>8.0%</td>
<td>4.2%</td>
</tr>
<tr>
<td>Task 3</td>
<td>233.3</td>
<td>15.1%</td>
<td>62.7%</td>
<td>18.4%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Task 4</td>
<td>232.3</td>
<td>10.8%</td>
<td>63.6%</td>
<td>20.1%</td>
<td>5.6%</td>
</tr>
<tr>
<td>Task 5</td>
<td>447.0</td>
<td>4.0%</td>
<td>81.0%</td>
<td>14.2%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Average</td>
<td>229.3</td>
<td>11.8%</td>
<td>69.6%</td>
<td>15.5%</td>
<td>3.1%</td>
</tr>
</tbody>
</table>

*Note.* The highest percentage for each of the regulative macro-processes is shown in bold font.
The lowest percentage for each of the regulative macro-processes is shown in bold italic font.

In regard to regulative processes, Task 5, the high-uncertainty escape room task with
sequential design, stood out because across all tasks it had the highest percentage of the
monitoring codes (i.e., 81%), and the lowest percentages of planning and evaluating codes (i.e.,
4% and 0.8% respectively). This was a reversal of the trend observed in Task 1, which had the
highest percentage of planning codes (i.e., 26%) but the lowest percentage of monitoring codes
(i.e., 57%). The finding about regulative macro-processes in Task 5 might indicate that groups
relied on the sequential design of the escape room as their plan for advancing through the task,
and thus did not develop their own plans. However, in this task, the groups did need to engage in monitoring in order to ensure successful outcomes and resolve uncertainty related to each puzzle and to breaking out of the escape room. It is probable that this task elicited the least need for evaluation because each puzzle had a unique design and only one correct code (i.e., solution), so the successful outcomes were obvious (i.e., the group cracked the puzzle code). Additionally, because the situational uncertainty in each puzzle was different, the detailed performance evaluations of one puzzle would be of limited benefit for solving the next puzzle.

The final consideration about differences in regulative processing is what processes each group engaged in during each task. Hence, I analyzed both the raw and the normalized frequency counts for each group by task (Figure 4.9). The overall raw frequency counts show the total number of regulative codes assigned to each group’s processes in each task. The key information to glean from the raw frequency counts is how the volume of regulative processing changed for each group in each task. The normalized frequency counts illuminate the rate of regulation for each group in each of the tasks. Hence, the frequency counts normalized for the duration of group’s on-task engagement enabled me to more accurately evaluate and compare the groups’ regulative engagements in each task. For the sake of completeness, I report both the raw and normalized frequency counts.
Figure 4.9. Overall raw and normalized frequency counts for regulative macro-processes by group.

The normalized frequency counts revealed patterns for each of the three groups across five tasks that are different from patterns that can be discerned based on raw frequency counts of regulative codes. Regulative processing for each of the three groups exhibited a different pattern across the five tasks indicating that different tasks stimulated the groups’ regulative processing in different ways. The UO group’s normalized regulation frequency counts showed a decrease from Task 1 to Task 2 and an increase in Tasks 3 and 4. The UO group’s regulation of learning slightly decreased from Task 4 to Task 5. This finding aligns with the predictions of uncertainty orientation theorists (e.g., Huber, 2003) that UO individuals should be more effortfully engaged in tasks of higher uncertainty and less engaged in low-uncertainty tasks.

The CO group’s normalized regulation frequency counts increased from Task 1 to Task 2 and then again in Task 3. The CO group’s regulative processing decreased from Task 3 to Tasks 4 and 5. With the exception of Task 5, the CO group engaged in regulation more than the other two groups. In uncertainty orientation theory, it is predicted that the CO individuals should be most engaged in situations of low uncertainty. Hence, my findings about the CO group’s regulative processing did not completely align with the theoretical predictions. Whereas the
finding that the group engaged in more regulative processing in Task 2 than in Task 1 aligns with the theory, the increase from Task 2 to Task 3, and relatively high processing in Task 4 do not. As I show through the qualitative analysis, discomfort caused by high-uncertainty Tasks 3 and 4 might have influenced development of complex group dynamics that ultimately shaped groups’ engagement and regulation of learning.

The Mixed group’s normalized frequencies increased from Task 1, the high-uncertainty task, to Task 2, the low-uncertainty task. Then the group engaged in less regulative processing in tasks of higher uncertainty, Tasks 3 and 4, and increased their regulative processing in Task 5. This finding indicates that some aspect of Task 5 might have stimulated the Mixed group to engage in more regulation than the previous tasks. There are no predictions in uncertainty orientation theory for people of moderate uncertainty orientations because they were traditionally excluded from the studies due to the unpredictability of their behaviors (e.g., Sorrentino et al., 2013; Szeto et al., 2011).

Figures 4.10 through 4.13 provide additional underlying details for the groups’ four regulative processes in each task. Across the five tasks, the UO group engaged in planning less than the other two groups. Their planning remained fairly stable across the first four tasks and decreased in Task 5. In all tasks, the CO group engaged in monitoring more than the other two groups, except for Task 5, in which the Mixed group engaged in monitoring more than the UO and the CO groups. This observed increase in the Mixed group’s monitoring was the main driver in the overall increase of their normalized frequency count from Task 4 to Task 5; the group’s enactment of planning and evaluating decreased in Task 5, and controlling remained unchanged from Task 4. Similarly, the UO group’s monitoring increased from Task 4 to Task 5, and the normalized frequency codes for the other three processes declined, resulting in a slight decrease
overall. Thus, for the UO and Mixed group, monitoring became increasingly important in Task 5. In contrast with the two other groups, the CO group’s monitoring decreased from Task 4 to Task 5. In each of the five tasks, the CO group’s normalized regulation frequencies for each of the four macro-processes increased and decreased synchronously. The two exceptions in this pattern were a decrease in controlling from Task 1 to Task 2 and an increase in evaluating from Task 3 to Task 4. The Mixed group’s engagement in controlling remained fairly stable over five tasks and lower than in the other two groups, indicating that this group did not need to adapt their course of action as often as two other groups. Changes in task uncertainty level also had little impact on the UO and Mixed groups’ engagement in evaluating. However, the CO group had wide oscillations in their evaluating, which culminated in Task 4 before dropping sharply in Task 5.

Figure 4.10. Planning: Raw and normalized frequency counts across tasks.
Figure 4.11. Monitoring: Raw and normalized frequency counts across tasks.

Figure 4.12. Controlling: Raw and normalized frequency counts across tasks.

Figure 4.13. Evaluating: Raw and normalized frequency counts across tasks.
Regulative targets. There were no differences in targets of groups’ planning. As I mentioned in a previous section, almost all of their planning efforts focused on task planning rather than on content planning. However, I found differences among groups in what they targeted with their monitoring, controlling, and evaluating (see Table 4.5). The UO group dedicated a greater percentage of their monitoring to the monitoring of their task plans (i.e., 43%) than the CO and Mixed groups (i.e., 34% and 35% respectively). Conversely, the UO group dedicated a smaller percentage (i.e., 21%) of their monitoring than the other two groups to the monitoring of task understanding (i.e., approximately 30%). This finding seems to indicate that the UO group generally might have been more confident in their task understanding and, because of that, needed to monitor it less than the other two groups. As I discuss in the qualitative findings, the UO group tended to pursue non-standard, creative task solutions, so it was not surprising that they needed to engage in effortful monitoring of their somewhat complex plans more than the other two groups.

Another notable difference was that the Mixed group dedicated a slightly greater percentage of their monitoring to the monitoring of content understating (i.e., approximately 10%) than the UO and the CO groups (i.e., approximately 8% each). As I show in the qualitative findings, through the series of five tasks, the Mixed group was characterized by the focus on obeying the task parameters and skillful use of the learning strategies. Hence, their greater attention to the content understanding aligned with their characteristic approaches to navigating through uncertainty.

For all three groups, the primary target of their controlling was task plan (see Table 4.6), which they adapted as needed to complete tasks at hand. Of the three groups, the CO group was the most engaged in controlling group members’ behavior; this group accounted for 70% of the
control behavior codes. However, this group did not engage in controlling of their emotions despite the group’s overall negative SE climate. In contrast, the group with the most positive group climate, the UO group, accounted for 85% of all controlling emotions codes. Thus, a regulative choice to control emotions when they are or have the potential to become less than optimal differentiated a group with positive climate (i.e., the UO group) from a group with a negative climate (i.e., the CO group).

The UO group dedicated approximately 7% of their control efforts to the control of task understanding, thus adapting their task understanding more than the other two groups. Combined with the previously discussed finding that the UO group monitored task understanding less than the other two groups, this finding indicates that this group in general was more confident in their task understanding but also more inclined to take action upon detected dissonance. The Mixed group differed from the other two groups by apportioning approximately 8% of their control to the control of environment, which was more than the other two groups. All of the Mixed group’s controlling of environment took place in Task 5, in which control of environment was a critical aspect of task success. The Mixed group was more apt at shifting targets of their control to align them to the challenges of the task. I revisit this finding later when I discuss differences by group by task to illustrate this process of target adaptation in more detail.

The CO group engaged in evaluating the most, and the Mixed group the least (see Table 4.7 and Figure 4.13). Approximately 25% of the CO group’s evaluating was evaluating through social comparison, which culminated in Task 4. In contrast, the Mixed group had no instances of evaluating through social comparison, and the UO group apportioned only approximately 5% of their evaluating to it. The UO group dedicated a larger portion of their evaluative efforts to evaluations of plan success and task completion than the other two groups. These findings about
differences in the targets of groups’ evaluations are fleshed out more in the section on qualitative findings when I discuss the salient themes related to the foci of groups’ regulation. Briefly, because the CO group focused on winning, they evaluated the most through social comparison. In contrast, the UO group focused on coming up with creative solutions, so targets of their evaluation (i.e., success of plan and task completion) supported their primary focus.

Next, I discuss differences in targets of social regulation of learning by tasks. As previously mentioned, in all tasks, groups’ planning efforts focused on task planning. The only two instances of content planning occurred in Task 1. Targets of groups’ monitoring varied by task (Table 4.13). In Task 1, a high-uncertainty task, groups focused mostly on monitoring their progress through the construction of the bioreactor. In Tasks 2 through 4, the groups were mostly concerned with monitoring their task plans. In Task 5, the main target of monitoring was task understanding, as a key prerequisite of the escape room completion. In all tasks, except Task 2, which was the low-uncertainty task, monitoring of content understanding received the least attention of the top four monitoring codes. In Task 2, the low-uncertainty task, participants devoted more attention to monitoring of the content understanding than to the monitoring of the task progress.

In summary, task uncertainty level made a difference in primary monitoring targets (i.e., what groups monitored the most). In some way, the primary targets of groups’ monitoring reflected the expected friction points for specific tasks: groups monitored aspects of the task that they recognized as critical for navigating towards successful task completion. In high-uncertainty tasks, Task 1 and Task 5, groups monitored their progress and task understanding respectively, rather than the task plan, because it was possible for them to covertly use some elements of the task as a proxy for a task plan. For example, in the first part of Task 1, groups had instructions on
how to build a bioreactor, and in Task 5, the sequential structure of the escape room guided them along. In Tasks 2 through 4, all of which involved design and building, the task plan became a primary target of monitoring because groups had to rely on their own capabilities to come up with and monitor both the building procedures and their execution. Importantly, it seems the low-uncertainty task, Task 2, afforded students more space for monitoring of content understanding than the other tasks, which required them to devote more attention to the monitoring of other targets.

Table 4.13

<table>
<thead>
<tr>
<th>Task</th>
<th>Raw count (M)</th>
<th>Monitoring codes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MTP (%)</td>
</tr>
<tr>
<td>Task 1</td>
<td>68.7</td>
<td>26.2%</td>
</tr>
<tr>
<td>Task 2</td>
<td>73.0</td>
<td><strong>30.1%</strong></td>
</tr>
<tr>
<td>Task 3</td>
<td>146.3</td>
<td>61.7%</td>
</tr>
<tr>
<td>Task 4</td>
<td>147.7</td>
<td>52.8%</td>
</tr>
<tr>
<td>Task 5</td>
<td>362.0</td>
<td>25.7%</td>
</tr>
<tr>
<td>Average</td>
<td>159.5</td>
<td>37.8%</td>
</tr>
</tbody>
</table>

*Note.* MTP = Monitoring task plan. MTU = Monitoring task understanding. MP = Monitoring progress. MCU = Monitoring content understanding. The highest percentage monitoring code in each task is shown in bold font.

On average, coders noted 35.5 controlling codes per group in each task. Targets of groups’ controlling activities reflected those aspects of the task groups decided to change upon detecting dissonance with the appropriate standards during monitoring. In each of the tasks, groups’ main focus was controlling the task plan, but there were variations in the second most prominent target elicited by the tasks (see Table 4.14). In Task 1, approximately 91% of all control codes were assigned to task planning, and the secondary target, task understanding, accounted for only approximately 7% of controlling. In addition to task planning, Task 2, the low-uncertainty task, elicited the need to engage in the controlling of task understanding. In
Tasks 3 and 4, the medium-uncertainty tasks, secondary targets of students’ control were their emotions and behavior. In Task 5, students dedicated approximately 11% of the controlling efforts to the control of environment.

There were no differences in the primary target of groups’ control (i.e., task plan was the primary target in all tasks), but the secondary targets did change as the groups worked on tasks of different uncertainty levels. Interestingly, groups engaged in control of emotions and behavior in tasks of medium uncertainty (i.e., Tasks 3 and 4), indicating that in those two tasks, emotions and behavior did not meet the groups’ standards and needed to be adapted to navigate through the task.

Table 4.14

| Most Prominent Controlling Codes as a Percentage of Controlling Total by Task |
|-------------------------------|---------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Task             | Raw count  (M) | CTP (% )  | CTU (%)   | C Env (%) | CE (%)    | CB (%)    | Other (%) |
| Task 1         | 15.3          | 91.3%     | 6.5%      | 0.0%      | 0.0%      | 0.0%      | 2.2%      |
| Task 2         | 9.0           | 74.1%     | 18.5%     | 0.0%      | 0.0%      | 3.7%      | 3.7%      |
| Task 3         | 43.0          | 86.0%     | 0.8%      | 0.0%      | 3.1%      | 3.1%      | 7.0%      |
| Task 4         | 46.7          | 85.7%     | 0.7%      | 0.0%      | 7.1%      | 6.4%      | 0.0%      |
| Task 5         | 63.3          | 77.4%     | 5.8%      | 11.1%     | 3.2%      | 0.0%      | 2.6%      |
| Average        | 35.5          | 82.7%     | 3.9%      | 3.9%      | 3.8%      | 2.6%      | 3.0%      |

Note. CTP = Controlling task plan. CTU = Controlling task understanding. C Env = Controlling environment. CE = Controlling emotions. CB = Controlling behavior. The second highest percentage controlling code in each task is shown in italic font.

Overall incidence of the evaluation codes was quite low, with the average of only 7.2 codes per group in a task (see Table 4.15). In all tasks, except for Task 2, groups engaged the most in the evaluations of the success of their plan. In Task 2, groups focused the most on evaluating task completion. In most tasks, groups’ secondary focus was on evaluations of their progress. The only exception was Task 4, in which groups engaged in more evaluations through social comparison than in the other tasks. In this task, other codes combined accounted for
approximately 21% of evaluation codes. A closer inspection of other evaluation codes revealed that this percentage could be attributed to groups’ engagement in evaluation of behavior and evaluations of work of others. Hence, students rarely engaged in retrospective evaluations and, when they did, their primary targets related to task (i.e., evaluating success of their plans and, in one task, evaluating task completion). Similar to what I found for the targets of control, there were few differences across tasks in the primary target of groups’ evaluations. There was little variation in the secondary targets as well; groups mostly evaluated task progress. However, Task 4, the slightly more difficult task of medium uncertainty, did elicit more engagement in evaluations through social comparison, as well as evaluations of behavior and evaluations of work of others. This finding indicates that with the higher level of task uncertainty, groups’ retrospective judgements shifted from their usual targets to targets concerning groups’ behaviors and competitive performance.

Table 4.15

<table>
<thead>
<tr>
<th>Task</th>
<th>Raw count (M)</th>
<th>Evaluating codes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ESP (%)</td>
</tr>
<tr>
<td>Task 1</td>
<td>6.0</td>
<td>44.4%</td>
</tr>
<tr>
<td>Task 2</td>
<td>4.7</td>
<td>28.6%</td>
</tr>
<tr>
<td>Task 3</td>
<td>8.7</td>
<td>80.8%</td>
</tr>
<tr>
<td>Task 4</td>
<td>13.0</td>
<td>43.6%</td>
</tr>
<tr>
<td>Task 5</td>
<td>3.7</td>
<td>45.5%</td>
</tr>
<tr>
<td>Average</td>
<td>7.2</td>
<td>50.9%</td>
</tr>
</tbody>
</table>

Note. ESP = Evaluate success of plan. ETP = Evaluate task progress. ETC = Evaluate task completion. E SC = Evaluate through social comparison. The highest percentage evaluating code in each task is shown in bold.

Finally, I discuss the most prominent differences in regulative targets by group by task (see Appendix D, Figures D.1 through D.3). A closer inspection of the UO group’s monitoring targets revealed that in Tasks 1 and 5, the group focused 35% of their monitoring on task
understanding (MTU). Over the series of five tasks, this group dedicated only about 21% of their overall monitoring to the MTU. Similarly, the Mixed group also engaged in more MTU in Tasks 1 and 5, dedicating 36% and 40% respectively, of their monitoring to it in contrast to 30% of their overall monitoring dedicated to MTU. Hence, in both of the high-uncertainty tasks (i.e., Tasks 1 and 5) the UO and the Mixed groups devoted a higher portion of their monitoring to their understanding of the task. The CO group behaved differently in Task 1, where the primary target of their monitoring was monitoring of task progress, which accounted for 50% of their monitoring efforts. However, the CO group behaved similarly to the UO and the Mixed group in Task 5. In Task 5, their primary target was also MTU, to which they dedicated 43% of their monitoring in that task, which was higher than the 29% they dedicated to MTU overall.

Groups differed the most in the primary targets of their monitoring in Task 2, the low-uncertainty task: the UO group’s primary monitoring target was task plan; the CO group’s primary target was task understanding, and the Mixed group’s primary target was content understanding. Differences in primary monitoring target in the low-uncertainty task indicate that each group foregrounded different aspects of the task. Whereas the UO group was most concerned with proper translation of their plan into action, the CO group was more focused on adequacy of their task understanding, and the Mixed group on the adequacy of the content understanding needed for the success in the task (i.e., slowing down a parachute). There were no differences in the primary targets of the groups’ monitoring in Tasks 3, 4, and 5. In Tasks 3 and 4, all three groups prioritized monitoring of task plans, and in Task 5, monitoring of task understanding. The UO group engaged in almost no monitoring of task understanding in Task 3, whereas for the other two groups, MTU was the second most prominent target. In Tasks 4 and 5,
secondary monitoring targets were the same for all three groups (i.e., task progress in Task 4 and task plan in Task 5).

There were no differences among the groups in the primary targets of the group controlling efforts: all three groups devoted the majority of their controlling efforts to the control of task plans in each of the five tasks (see Figure D.2). However, as I previously stated, the Mixed group engaged in less controlling than the other two groups, as is evident from the magnitude of their normalized controlling counts across the five tasks. The most notable differences in groups’ secondary controlling targets were the CO group’s engagement in control of behavior in Task 4, whereas, for the UO and the Mixed group, the secondary target was controlling their emotions in this task. This finding is interesting because of the frictions that culminated in the CO group in Task 4, yet the group took no action to control their emotions, nor did they openly address the specific behavior (i.e., the incident) that caused friction. Instead, they focused their controlling on directing the behavior of group members during work on the task through coRL. Another difference worth pointing out is the quality of the Mixed group’s engagement in the control of environment in Task 5. Whereas the CO group engaged in the control of environment just as much as the Mixed group, the Mixed group was more effective and systematic in their efforts to control the environment in Task 5.

The three groups differed in what they targeted through their evaluations (see Figure D.3). Whereas the UO and the CO groups evaluated at least two different targets in each of the five tasks, the Mixed group engaged in evaluations of a single target in all tasks except in Task 4, in which they evaluated two targets (i.e., task progress and work of others). Because of very low raw and normalized frequencies for evaluating, in this section, I review the groups’ primary targets of evaluating.
The UO group focused on evaluating success of the plan as their primary target in all tasks, except for Task 2 in which their primary target was task completion. The CO group’s primary evaluation targets were the same as the UO group’s in Tasks 1, 3, and 5; they, too, focused on evaluating success of the plan. But, in Task 2, their primary target was evaluation of task progress and, in Task 4, most of their evaluating efforts focused on evaluating through social comparison. In Task 4, the CO group was the only group to engage in evaluations of behavior, which was their tertiary evaluation target in this task. The Mixed group’s primary evaluation target was evaluation of task progress in Tasks 1, 4, and 5 and evaluating success of the plan in Tasks 2 and 3. In Task 4, the Mixed group also engaged in evaluating work of others, thus engaging in retrospective evaluation of the work products of other groups (e.g., “That’s brilliant”) but without comparison elements that characterized evaluations by the CO group in the same task (e.g., “Theirs is like ours but better”).

In summary, targets of a group’s evaluations reflected that group’s dominant focus in collaborative problem-solving and their internal dynamics. This was most evident in Task 4. The UO group remained focused on evaluating success of their plan, which typically involved non-standard solutions. However, the CO group differed from the two other groups by engaging in evaluation through social comparison and evaluations of group members’ behavior; these targets were a reflection of the group’s internal dynamics and increasing focus on competition. The Mixed group engaged in evaluations without the comparison component; a reflection of their approach focused on fulfilling task parameters and their positive group dynamics.

The key takeaways from the quantitative analysis for Research Question 2 were that the three groups differed in on- and off-task engagement, group dynamics, and SE climate, as well as in regulative processing over the series of five tasks. The UO group, which spent the most time
on-task and the least time off-task, was characterized by a positive SE climate, as was the Mixed group. The CO group, which spent the least amount of time on-task and the most off-task, had a negative SE climate. The CO group’s off-task engagement and negative SE interactions culminated in Task 4, the medium-uncertainty task. Task 5 was characterized by the absence of off-task engagement in all three groups.

With respect to regulative processing, differences in the processing and targets of groups’ regulation reflected groups’ differing foci, as well as the unique task-related challenges they encountered (e.g., the need to control the environment in Task 5). For all three groups, the primary planning target was task planning, but the UO group engaged in planning less than the other two groups. Primary targets of the groups’ monitoring varied among the groups and with the task uncertainty levels, indicating the groups were prioritizing different aspects of the task. One of the interesting findings was the UO and the CO groups engaged in more controlling than the Mixed group, with task plan being the primary control target for all three groups. The UO group, which was characterized by a positive SE climate, engaged in control of their emotions the most, but, despite the negative SE climate, the CO group did not. The Mixed group controlled their environment more than the other two groups, especially in Task 5. Engagement in evaluating was relatively low and stable in the UO and the Mixed groups, but the CO group’s evaluating varied over tasks, peaking in Task 4. The CO group engaged in evaluating through social comparison more than the other two groups, whereas the UO group’s evaluating targets were success of plan and task completion. I connect to and further contextualize these findings in the following section on qualitative findings.
Qualitative findings. In this section, I describe three salient themes for each group that illustrate key differences in the groups’ regulation of learning. For the UO group, the main themes were active pursuit of uncertainty, reliance on support within the group, and focus on creative solutions. For the CO group, the main themes were avoidance of uncertainty, reliance on the appeals to the authority to resolve uncertainty, and focus on winning. For the Mixed group, the dominant themes that characterized their regulation of learning were being untroubled by uncertainty, focusing on task parameters, and skillful use of learning strategies. It is important to note that the key themes identified for each group closely related to each other and worked synergistically to produce regulation of learning unique for that specific group. Moreover, whereas two of the themes per group were based on data largely consistent across tasks, in each group there was a third theme that arose from analysis of data across tasks. As the groups engaged in the series of five tasks of varying uncertainty, for the UO and the CO groups, the respective primary focus on creativity and winning became apparent. For the Mixed group, the series of five tasks of varying uncertainty levels helped illuminate the group’s skillful use of the learning strategies. This finding informs an understanding of which aspects of collaborative groups’ social regulation of learning might be waxing and waning and how with the changes in task uncertainty level and structure for groups of different uncertainty orientations.

UO group: Active pursuit of uncertainty. The first salient theme for the UO group was their active approach to obtaining new information and resolving uncertainty involved in the task. This active approach manifested as self-initiated exploration directed at resolving some aspect of uncertainty identified in the task. In their efforts, the group often treated the task requirements as pliable, either going beyond them or choosing to ignore them. In Excerpt 12,
from Task 1, the group prepared their bioreactor container and were getting ready to select their materials.

*Excerpt 12. UO group: I Googled compost for some reason.*

74 Julie: I Googled compost for some reason. You're supposed to have a 50
50…

75 Rose: Oh, that's good.

76 Julie: …of brown carbon to nitrogen, which is brown and green…

77 Emma: Okay. And I figured, too, we don't want to ... Since they kept
talking about all the air pockets-

78 Julie: …layers.

79 Emma: -We want to make sure there's a mix of it, and also that’s not
squished in.

80 Julie: Yeah. Right.

In this excerpt, in Turn 74, Julie shared with her group members that she had proactively researched compost makeup, going beyond the task requirement, and she provided the group with the additional information about carbon to nitrogen ratio they could use to put together their bioreactor (i.e., Turn 76). Rose welcomed this new information and expressed her approval for this action (i.e., Turn 75). In Turns 77 and 79, Emma contributed to the group’s discussion by adding her idea about the need to ensure that there were air pockets in the bioreactor. Thus, the group checked their content understanding prior to choosing the ingredients and putting them into the container. They proceeded as equipped with this new knowledge based on Julie’s research about the mix and layers of ingredients and Emma’s statement about air pockets and leaving the space between the ingredients. They jointly and effortfully monitored their
understanding of what characterizes good compost and made a plan for a bioreactor that included layers and air pockets. The regulative processing that took place and the product of it (i.e., the plan that included layers and air pockets) differentiated this discussion as a regulative episode rather than simple engagement in knowledge construction.

In Excerpt 13, from Task 2, the group conducted a third and final drop of their parachute. For each of the three trials, Rose climbed up on her chair and dropped the parachute. The group members noticed an irregularity in the third trial and decided to repeat it.

*Excerpt 13. UO group: Let’s do it again.*

81  Sarah:  Okay. 3, 2, 1, drop.
82  Emma:  Stop.
83  Rose:  It hit me.
84  Sarah:  1.48. That one was *really* a lot louder. (*Julie puts the fan back on the counter. Rose comes down from the chair.*)
85  Rose:  We can do that again, cause that one hit me. And it bounced off. (*Julie picks up the parachute off the floor and gives it back to Rose.*)
86  Emma:  Okay, let's do it again. (*Rose climbs back on the chair with the parachute.*)
87  Julie:  Mistrial.
88  Sarah:  Yeah, ‘cause you *might*ve... it's the line of fire.
89  Rose:  I slowed it down, or I sped it up.
90  Julie:  Yes.
91  Sarah:  3, 2, 1, drop. (*Rose drops the parachute again.*)
Emma: Stop.

Sarah: Wow, that one was 2.1

Emma: Heck, yeah. *(Emma writes it down on Rose’s and her own sheet.)*

In Turn 83, Rose proclaimed that the parachute hit her as it fell. Sarah, the group’s timer, announced the time for the drop and confirmed that there was something wrong with it (i.e., it “was really a lot louder”). In Turn 85, Rose suggested repeating the trial. In Turns 86 through 88, the group quickly came to a consensus on performing the trial again. Emma agreed to it (i.e., Turn 86). Julie indicated her agreement by declaring a “mistrial” (i.e., Turn 87), and Sarah also agreed that Rose might have affected the speed of the parachute. In Turn 89, Rose raised an uncertainty about the way in which the parachute’s speed might have been altered, and Julie (i.e., Turn 90) agreed with Rose’s statement. The group resolved this uncertainty by conducting another drop and achieving a slower time (i.e., 2.1 s versus 1.48 s in the first attempt).

The UO group’s active resolution of uncertainty about the validity of the drop in Excerpt 13 stood in a stark contrast with a conversation that took place in the CO group (i.e., Excerpt 5) in which the CO group ignored the uncertainty. In the CO group, Alice, in Turn 27, noted that the drop was “a quick one” and Kerry, in Turn 28, noted that the parachute strings were twisted and expressed doubt about the validity of the trial. However, the group avoided discussing the potential impact of the invalid trial any further and moved to calculate the average.

In Task 3, all the groups in the class, except for the UO group, used the air in their bags to cushion the egg. Following the first egg drop, the instructor challenged the groups to redesign their containers to include no air in the bag. At the beginning of Excerpt 14, from Task 3, the UO group evaluated the success of their own egg drop container design, which included two design
elements that no other group used: a paper towel parachute with no air pillow in the bag with their egg.

Excerpt 14. UO group: Let us try it again a different way.

95  Sarah:  I think if we had had a stronger thing for our parachute…

96  Emma:  Like a garbage bag…

97  Sarah:  …that would have worked.

98  Rose:  Or bigger parachute, you know, like a piece of paper.

99  Sarah:  The fact that we split up our paper towels, might have been our mistake.

100  Emma:  Yeah.

101  Julie:  Also, we might want to cut another hole in the cup.

102  Emma:  I will say next time, maybe… there is no need…just drop the egg. [crosstalk 00:03:50].

103  Rose:  Let us wrap him in this, so we do not watch him die. (Emma, Julie, and Rose laugh.)

104  Julie:  Wrap him in one paper towel.

105  Rose:  But it was Bounty.

106  Julie:  Bounty, take this.

107  Emma:  We do not have to go again because we did not have air.

108  Julie:  Do we?

109  Sarah:  No, we did great.

110  Rose:  Yay.
Julie: Let us try it again a different way. (All laugh.)

Emma: (Emma looks around the classroom.) So, if they are doing it again, we might as well just... (Emma gets up and reaches for their materials.)

Julie: What if we try it again with the three strings? I think we could do that.

Emma: With the three strings?

Rose: Yeah. Do another string. Maybe over here? (Rose touches the plastic cup to indicate possible placement for the additional string. Emma puts their egg back into the cup.)

In Turns 95 through 100, the group discussed weaknesses of their parachute design, which did not produce any visible slow-down for their egg container. In Turn 101, Julie suggested adding a hole in the cup, implying that the hole would serve to attach one more string to the parachute. In Turn 102, Emma suggested eliminating the parachute altogether. In Turns 103 through 105, group members joked about simply dropping an egg wrapped in a single paper towel. Then the group realized they did not need to participate in the redesign because they did not use air in their bag. Julie’s suggestion to try it another way (i.e., Turn 111) was welcomed with friendly laughter, and the group moved to redesign their parachute by adding a third string (i.e., Turns 112 through 115).

The blog posts of the UO group members provided additional insight into the importance of active pursuit of uncertainty for these students. Sarah wrote in her science autobiography: “The focus of science should be this, therefore: to explore the unknown together. To invoke curiosity, to learn how and why things are the way they are, and to take ownership of that
knowledge.” In her science autobiography blog post, Julie fondly remembered a failed experiment in elementary school science class, which led to additional research:

The unexpected happened and we got to investigate it. This curiosity was part of who I was and am and being able to use it in school made it feel like I was exploring a creek with my parents (as I loved to explore and ask questions, play and learn wandering about the creek flipping over rocks).

Emma similarly reflected on her engagement in science investigations during her early schooling: “These tastes of exploration fed deeply into my curious nature.” Thus, this group of participants had a propensity for active investigation and resolution of uncertainty. This group’s pursuits of resolution of uncertainty and related decision-making shaped the group’s social regulation of learning, leading them to engage in the regulative process of controlling more than the other two groups. Quantitative data showed that the UO group accounted for almost half of all instances of controlling. As they exercised collective agency to pursue uncertainty, the group members relied on each other and support within the group.

**UO group: Support within the group.** The UO group relied on support within the group in their regulation of learning. They engaged in more internal than external help-seeking (i.e., 11 and 8 instances respectively), and did so more than the CO group (i.e., 7 instances of internal help-seeking) and the Mixed group (i.e., 2 instances of internal help-seeking). Additionally, group members extended sincere offers of help and support to each other. Thus, the support within the group unfolded organically and in a friendly manner. Excerpt 15 illustrates an instance of internal help-providing and help-seeking from Task 1. In Excerpt 15, Emma tried to assemble two parts of the bioreactor, but she was unsure how to do it.

**Excerpt 15. UO group: Can you just like...**

116 Emma: *(Emma attempts to put the top of the bioreactor into the wider part of it, but it is not fitting easily.)* I don't know how to ... Maybe we
just use tape to fix that part. \(\text{(Rose looks on, as Emma and Julie work on the bioreactor.)}\)

117 Rose: **Could** we cut a slit in it and tape over the ... \(\text{(Rose leans in and points to a spot on the bottle.)}\)

118 Emma: Ooo! Yes. \(\text{(Rose takes the scissors and cuts a slit in the bottom part of the bioreactor. She then cuts a piece of tape and tries to apply it to the slit.)}\)

119 Rose: Can you just like…

120 Julie: Oh, okay. \(\text{(Julie holds the bottle in place to help. Rose tapes the slit.)}\)

In Turn 116, Emma expressed uncertainty about how to attach the two parts of the bioreactor together. Rose helped by suggesting a potential solution (Turn 117), which Emma accepted (Turn 118). Rose then took over the bioreactor from Emma to cut the slit in the bottle and tape it. In Turn 119, Rose asked Julie for help in stabilizing the bottle. Together, by offering help and asking for help, the group members were able to execute their plan.

The group members’ offers of help to each other typically arose from monitoring of task progress or task plan and led the group to jointly resolve some aspect of uncertainty. In Excerpts 16 and 17, from Tasks 1 and 4 respectively, students offered help to their group members when they noticed the person was struggling and progress was stalled.

*Excerpt 16. UO group:* Do you need help holding anything, Emma?

121 Julie: Do you need help holding anything, Emma?

122 Emma: \(\text{(To Julie:) Do you think I taped that enough, or I don't know what [inaudible]}\)
Julie: I think maybe it's air bubbles. We have to make sure it is airtight.

Emma: Oh, airtight…

Excerpt 17. UO group: Do you want me to hold it?

Rose: Do you want me to hold it?

Julie: Is that enough tape?

Rose: Oh yeah, definitely. I feel like you could even use less for this one. (Rose holds the straw in place and Julie attaches it to the base using tape. Sarah works on the other piece of their construction.)

Julie: Okay, great. I'm going to go in there.

Both Julie (i.e., Turn 121) and Rose (i.e., Turn 125) were respectful of the other group member and aware of the possibility that their colleague might not want or need help. In both cases, these polite and concerned offers served as openings to articulate (i.e., Turns 122 and 126) and resolve uncertainty about the current course of action (i.e., Turns 123–124, and 127–128).

Internal support was also critical for helping the group overcome difficult moments in their work. In Excerpt 18, from Task 5, the UO group discussed guessing a random number after repeatedly failing to solve a puzzle.

Excerpt 18. UO group: I'll tell you how many digits it is.

Sarah: I think we're better off just guessing random numbers at this point.

Emma: Yeah. This is so random. (Sarah, Emma, and Julie laugh in frustration. Julie pulls out her chair and sits down.)

Rose: I've got to sit down too. (Rose pulls out her chair and sits down.)
Sarah: We're never going to get it though if we're just guessing numbers.

Julie: If four college educated women can't figure this out…

Rose: Okay, let's think about this. *(Rose picks up one of the pieces of paper that were in the envelope and starts looking at it.)*

Emma: I'll tell you how many digits it is.

Sarah: It's been a rough day in science. *(Sarah and Julie laugh.)*

Emma: Okay, it's going to be six digits.

In Turns 129 and 130, Sarah and Emma realized that their plan had not worked out and discussed randomly guessing numbers. In Turn 132, Sarah backtracked, saying that they would never solve the code by random guesses. In Turn 133, Julie implied the group members should trust their capabilities (i.e., they are “four college educated women”). Rose reacted to this by saying “Let’s think about this,” and Emma helped by telling the group how many digits there were in the code (Turns 135 and 137). The group members’ statements built on each other to produce a desired action of returning to task and thinking about the puzzle in front of them.

Following this excerpt, about one minute later, Rose realized that their group was supposed to calculate the C:N ratio for each of the three batches of ingredients, thus setting the group on the right path to solve the puzzle.

In their blog posts about the escape room task, in which the group struggled the most and ultimately needed the teaching assistant’s help to solve the last puzzle, the group members expressed their aversion to external help-seeking and preference for other means to move forward in the task. Rose wrote in her escape room blog post:

I didn’t like how at moments when we got stuck, there weren’t really any ways to get hints except for asking the instructors. It would have been a nice addition I think for there to be several hint options to use along the way on the google form because the content was harder than I thought it would be!
The UO group: Focus on creative solutions. The UO group thrived on pursuing out-of-the-box thinking and creative solutions even if that meant pushing the boundaries of the prescribed task parameters or slowing progress through the task. This approach was evident starting with the baseline task in which the groups sorted cards based on whether the object shown on the card was compostable, reusable, recyclable, or disposable. At the start of the task, per Julie’s suggestion, the UO group added a new category called TerraCycle to the four instructor-specified categories. In the following excerpt, the group used the new category for the first time.
Excerpt 19. UO group: Let’s TerraCycle it.

138  Rose:  *(Rose taps the two unsorted cards on the table.)* I don't know about those. I throw all this in the trash.

139  Emma:  I mean, I definitely would throw them away.

140  Julie:  If the aluminum foil is dirty, its trash, but if it's not then you could TerraCycle. Honestly, I think you could TerraCycle it.

141  Emma:  Okay, let's TerraCycle it, yeah. *(Rose moves the card into a TerraCycle pile.)* We're going to be the only group with TerraCycle. I'm so proud. How can we use these? So, are these K-Cups? *(Emma picks up the last card and looks at it closely.)*

142  Rose:  Can you recycle it?

143  Julie:  You could put the coffee grounds in the compost and TerraCycle the top lid, and then recycle the – *(Julie smiles as she speaks.)*

In this excerpt, Rose expressed uncertainty about the appropriate category for aluminum foil and the Keurig cup. In Turn 140, Julie steered the group’s understanding of how to dispose of the aluminum foil (i.e., it can be TerraCycled). Emma and Rose accepted this suggestion (i.e., Turn 141), and Emma expressed pride in the originality of their approach in using a new category. Julie then suggested yet another creative solution in Turn 143, namely, separating the Keurig cup into parts and then separately disposing of each part, TerraCycling the lid. During the subsequent whole class reporting out, Emma raised her hand: “I would like Julie to introduce the sub-category we added.” Upon Julie’s explanation of the TerraCycle category, the instructor added it to the list of categories on the board, thus the group was effective in contributing a novel idea to the whole-class understanding of recycling. In contrast, the Mixed group, which also
internally discussed the TerraCycle category, did not discuss the novelty of adding one more category and did not share it with the class.

The UO group’s focus on creative solutions was also evident in the following excerpt from Task 2, in which the groups worked on changing one design parameter of their parachute with a goal of making it fall slower. This excerpt took place after the whole class brainstormed possible ways to slow down the parachute and generated a list of ideas. Instead of pursuing one of the ideas from the list like all of the other groups, the UO group pursued Julie’s novel idea of increasing the air resistance.

Excerpt 20. UO group: Change the resistance.

144 Julie: Okay, I have a crazy idea.

145 Sarah: Oh, gosh. (Sarah smiles. Julie chuckles.)

146 Julie: See that fan over there? (Julie nods in the direction of a fan on the counter in the back of the classroom.)

147 Julie: Change the resistance so it blows up…

148 Rose: Yeah!

149 Julie: … and then we drop it from the same height, it'll go slower. (All four laugh.)

Similarly, in Task 3, unlike other groups in the class, the UO group decided not to use the air in their bag (e.g., Excerpt 7 and Excerpt 21), and in Task 4, instead of creating a tower-like construction, they decided to create a hammock-like design to cradle the tennis ball. The group pursued the creative solutions even though they were aware that they carried more risk than more common approaches, as shown in Excerpt 21 from Task 4.
Excerpt 21. UO group: The road less traveled.

150 Instructor: How about that table?

151 Sarah: Oh, we are almost done. Ours [the egg] is 100 percent going to crack. We tried to take the road less traveled.

152 Rose: We did.

Similar to Excerpt 19, Line 141, when Emma expressed pride in their idea of adding a new category, group members expressed being proud of their creativity and ideas on other occasions. For example, in Except 22, the group assessed their hammock idea as great and engaged in playful comparisons of their solution to the solutions built by the other groups.

Excerpt 22. UO group: Why are our ideas always so great?

153 Sarah: Why are our ideas always so great?

154 Julie: Because we're the best.

155 Rose: Isn't it cute? Don't you wish yours looked like this?

156 Julie: (Julie sings). Don't you wish your hammock looks more like ours?

157 Rose: Although the bottom's coming out. (She laughs.)

In Task 5, however, the structure of the escape room emphasized careful reading of the puzzle materials to discern useful clues needed to progress through the task. This task elicited different reactions from the UO group than the previous tasks. For the first time in the series of the five tasks, the group needed to engage in monitoring and control of their motivation due to their slow progress and frustration. Moreover, they explicitly connected their frustration to not being able to pursue creative solutions as they did in previous tasks. At the time when Excerpt 23 occurred, the group spent more than 15 min working on a single puzzle.
Excerpt 23. UO group: We give up.

158 Emma: This last number, this is the only thing that will work.

159 Julie: If this is wrong…

160 Emma: We are doomed.

161 Sarah: We give up. [crosstalk].

162 Emma Trash the computer! (All laugh.)

163 Sarah: No, but I also feel like this is limiting our creativity... We're so creative when we are together. Like our creativity is boundless.

164 Julie: I know! (Rose nods.)

165 Emma: I literally wrote that about our creativity in my thing before this ...

23. Okay. This is it and it didn't light up so it's not right. It's not right. (Emma laughs in frustration.)

In Turn 158, Emma entered the last code number into the computer and acknowledged that was the last option based on the set of numbers they were given. Julie, Emma, and Sarah articulated the group’s diminishing motivation (Turns 159 through 162). In Turn 163, Sarah pointed out that their frustration also came from not being able to rely on the group’s creativity, which had been thwarted by the task’s structure. In Turns 164 and 165, the other group members agreed with her.

A change from the tasks that permitted space for creative pursuit of solutions to a task in which deviating from the expected path was maladaptive foiled the UO group’s typical approach to the problem-solving and their progress through the task. In Task 5, the group had to monitor and control their motivation and emotions to persevere on the task (e.g., Excerpt 23, Turns 159–
They were the last group to complete the escape room, spending around 10 minutes more on it than other groups.

I found additional support for this theme in the secondary data sources. In her blog post about the bioreactor building, Emma stated that scientific uncertainty left room for creativity but also recognized that for some students, that uncertainty might be difficult to grapple with:

Since we were only provided with instructions on the building the actual bio-reactor, it left numerous variables up in the air, including: amount of water, ratio of green to brown material, types of green and brown material, amount of total compostable material. While this leaves room for plenty of creativity, it can be intimidating to younger students that desire more direction.

In her pre-task response to Task 2, Rose wrote: “I like the creative aspect of this task and feel that our group has strength in this particular area.” Julie reflected on creativity and connected it to productive failure and adaptation in her response to the question prior to Task 4: “I am very confident that I know how to complete this task because I have engineering skills and creativity and am willing to try + fail + adapt to that.”

According to uncertainty orientation theory, UO individuals orient towards novel solutions because these solutions offer an opportunity for them to master the uncertainty and learn something new (Sorrentino & Roney, 2000). In terms of UO group’s social regulation of learning, my finding about the UO group’s focus on creative solutions indicates that in tasks with an open structure, the group’s initial task perceptions and goal setting were informed by their awareness of atypical solutions. According to Winne and Perry (2000), students’ awareness of non-standard solutions during initial goal setting is one of the hallmarks of proficient self-regulated learners. Moreover, for the UO group, the novelty of the solution was an important part of the group’s joint standard against which they monitored and evaluated their work. In Task 5, in which the task structure was firm and sequential, with only one correct solution for each
puzzle, the group’s normal approach to problem-solving was thwarted and their progress through the task was slow compared to the other groups in the classroom.

In summary, the three themes that differentiate and describe the UO group’s regulation of learning (i.e., active pursuit of the uncertainty, support within the group, and focus on creative solutions), align well with the predictions of uncertainty orientation theory related to UO behavior (e.g., Brouwers & Sorrentino, 1993; Huber et al., 1992; Sorrentino & Roney, 2000). In terms of the social regulation of learning, these themes offer a new insight into how and why the UO group set their collective goals and standards, engaged in controlling more than the other two groups, and relied on their group members to resolve uncertainty rather than on external help. In the following section, I discuss the dominant qualitative themes for the CO group that illuminated social regulation of learning very different from that of the UO group.

**CO group: Avoidance of uncertainty.** The first salient theme for the CO group was the avoidance of uncertainty. The group’s avoidance of uncertainty manifested as withdrawals from engagement with the group members who articulated uncertainty and situations in which the uncertainty arose. Importantly, the group did not lack general motivation and interest as was evidenced by group’s focus on winning (i.e., the third salient theme for the CO group). Rather, it was that the uncertainty served as a trigger for group members to orient away from active pursuit of its resolution. In the following example from Task 1, the group attempted to add water to their bioreactor. Laura was unsure of how to read the water level in the 50-milliliter beaker (i.e., Turn 167). Instead of helping Laura resolve this dilemma, Alice (i.e., 168) and Parker (i.e., 180) avoided dealing with the uncertainty.
Excerpt 24. CO group: Is this one milliliter?

166 Alice: Ours is definitely the coolest looking. All right, how much water we got?

167 Laura: Fifty milliliters, or not milliliters. It says 50 plus one milliliter, so it's 51 milliliters? Is this milliliters? (Laura holds up a beacon with water.)

168 Alice: I can't read that stuff, sorry. (Alice turns away and starts writing on her sheet. Laura and Parker are looking at the beacon trying to figure out how to measure liquid.)

169 Laura: Is this one milliliter, because it's 50?

170 Parker: I have no idea.

171 Laura: How much did you work on? How much [crosstalk].

172 Parker: Let's just say-

173 Laura: I'm going to ask her because I want to make sure. (Laura gestures towards the instructor with her head.) I want to do less now. I want to do 30. She said not to level off. That's [crosstalk]. Instructor, could you explain this to me? It says 50 to one milliliters, so it's 50... This is one milliliter?

174 Instructor: (The instructor approaches their table.) That's 50 milliliters.

175 Laura: This is 50 dot, dot one.

176 Instructor: Let me see what it says on it.

177 Laura: I was [inaudible].
Instructor: Yeah. One milliliter increments. What it's saying is each part of those lines is one milliliter.

Laura: Perfect. Okay. (At 30:12 mark, Laura goes back to the sink. Parker walks ways from the table as well.)

In Turn 168, Alice excused herself and started writing on her sheet, leaving her two teammates to deal with the reading of the markings on the beaker without her. Although she initially looked at the beaker with Laura, in Turn 170, Parker also made no attempt to figure out the markings on the beaker and offered no help. In Turn 173, Laura then turned to the course instructor for help and an explanation. In this turn, Laura also expressed a unilateral decision to use 30 ml of water. Hence, the low group cohesion propagated and resulted in individual rather than group decision-making.

In Excerpt 25, from Task 2, the CO group waited for the whole class discussion about the first parachute drop. Kerry tried to initiate a conversation about the redesign task, but the rest of the group members avoided engagement and instead started an off-task conversation.

Excerpt 25. CO group: I don’t know how to make it slower.

Kerry: So, we want to make it slower. (Kerry holds up their parachute by the clothes pin. Parker yawns. Alice yawns. Laura looks at the paper in front of her, and Parker looks away at another group.)

Alice: (Talking to Laura:) I thought y’all said she was awful. (Alice starts another off-task conversation about the camping trip.)

Kerry: (Kerry removes the clothes pin and lets the plastic sheet fall onto the table by itself. She then attaches the pin back to one of the strings and lets the sheet drop onto the table again.)
I don’t know how to make it slower.

(Kerry puts the parachute in the middle of the table. She picks up her phone. The other three students continue their off-topic conversation. Kerry joins in a few moments later.)

In Turn 180, Kerry stated the group’s goal and then used the learning strategy of preliminary testing as a proof-of-concept test, dropping the plastic sheet without the pin and with the pin attached. Her attempt to find a way to slow down the parachute is an example of SRL, because other group members did not respond to her, disengaging from the task and engaging in an off-task conversation. Kerry quickly gave up and disengaged from the investigation as well. In Turn 182, Kerry noted she did not know how to make the parachute slower and joined the others in off-task conversation.

Excerpt 5, which I provided in the findings for Research Question 1, includes another example of avoidance of uncertainty from Task 2. In Turn 28, when Kerry expressed uncertainty about the validity of the parachute drop trial, Laura simply ignored it (i.e., line 29) and forged forward to calculate the group’s average. Other group members, including Kerry, did not object, and the group avoided dealing with the identified issue. Hence, in the CO group, avoidance of uncertainty, ignoring, and absence of support from the group members formed a maladaptive pattern of engagement.

In Task 4, avoidance of uncertainty reached a new level when approximately three minutes into the task, Alice found a way to limit her task involvement, making her contribution insubstantial. In Excerpt 26, the group started building their straw tower. Alice had already built a single rectangular frame made out of four straws.
Laura: Why don't you do another one of these... *(Laura taps the frame in front of Parker.)*

Alice: Okay.

Laura: And then we'll...

Parker: Tape them together.

Laura: …Do these like this and we'll tape them.

Alice: Okay. Why don't I be in charge of doing this? Because I don't know anything else, so… *(Kerry mockingly laughs at Alice’s statement and looks away from the group.)*

Laura: Okay, so we'll do... You make another one of those.

Alice: Cool. Cool, cool, cool. I can do that.

In Turn 183, Laura asked Alice to build an additional frame. In Turns 185 through 187, Laura and Parker controlled the group’s plan, deciding that they would tape the frames together. Alice assigned herself a limited role of frame builder, claiming that she did not know anything else (i.e., Turn 188), thus effectively limiting her participation for the remainder of the task and leaving the resolution of any potential issues to others. Kerry’s mocking laughter indicated she recognized Alice’s self-proclaimed inferiority as a way to avoid being accountable to the group and mutually responsible for the outcome of the task. Alice’s statement at the end of the task supported this interpretation: “Yeah, I thought that was going to fail so hard and y'all killed it.” Additionally, in Task 4, Parker also engaged in a limited way, mostly just helping by holding the construction in place.
Excerpt 27, from Task 4, illustrates an incident that followed the group’s discussion of whether or not the task called for using all the straws and if the current plan was using too many straws.

*Excerpt 27. CO group: We could really use like a million of these.*

191 Kerry: Are we going to use too many straws doing it that way?
192 Laura: Do we have to use all of them?
193 Kerry: Yeah.
194 Alice: Yeah.
195 Laura: We have to use all of them?
196 Kerry: But also like we've been-
197 Laura: **Should** we make a wider base?
198 Alice: We can.
199 Kerry: *(Reaches in front of P11 and picks up a bunch of straws. She drops them into the construction.)* Y'all, we **could really** use like a million of these. *(Kerry laughs. Alice smiles big, but avoids looking at her group members. Laura looks to be in disbelief but then flashes a quick smile.)*

200 Parker: *(In response to Laura:) Yeah.
201 Laura: **Should** we make a wider base? *(Parker picks up the straws Kerry dropped into their construction and puts them on the side.)*

202 Kerry: How? *(Nobody responds to her.)*
Alice: *(Speaking to Laura:)* No, because then we would have to use more straws to do it, right or no? *(Alice motions with straws across the top of the frame.)*

Kerry: Yeah.

Parker: *(To Laura:)* Yeah. I think this is fine.

Kerry: I think that's fine.

In Turn 191, Kerry questioned if the group’s current course of action was going to use up too many straws. In turn, Laura attempted to clarify the task parameter of using all the straws (i.e., Turns 192 and 195). Alice and Kerry confirmed that indeed this was required (i.e., Turns 193 and 194). Laura proposed widening the base of their construction (Turn 197), and Alice responded with her support (Turn 198). In Turn 199, Kerry suddenly picked up and dropped a handful of straws into the part of the construction that was already built. Interestingly, no group member openly addressed this transgression. Instead, the group chose to ignore Kerry for the next several minutes and simply stopped responding to all of her statements while still conversing with each other.

I hypothesize that it was this disengagement and maladaptive behaviors that led to the notable drop in the CO group’s regulation of learning in Task 4. Another possible explanation for a decrease in the group’s regulation of learning could be the group’s proficient and smooth task performance that necessitated no engagement in regulation. However, I found no evidence in video-observation of group’s performance to support this interpretation.

My finding about the group’s avoidance of uncertainty and disengagement as the task uncertainty level increased was supported by the secondary data sources. In her Task 4 pre-task response, Alice expressed a lack of confidence in her ability to contribute to the group: “I’m not
as confident as I usually am with this task because I am not really good at engineering design and don’t know how much I’ll be able to contribute to my group.” Prior to Task 4, Kerry wrote: “I think we will try & probably be able to figure it out as a team, but this task seems difficult and challenging.” In her response to the pre-task question for Task 1, the high-uncertainty task, Alice wrote about her lack of confidence in her ability to deal with encountered open-ended tasks: “If I ever had to do something like this by myself I would freak out, because I’m not really good at sitting down and problem solving to figure something out.”

Science autobiography blogs of all four students illuminated their negative dispositions toward science in general, which, according to the students, became stronger as they got older, and science got more challenging. Kerry remembered her increasing frustration as her Kindergarten through Grade 12 science classes became more difficult: “Later in school as science classes became more advanced, I remember becoming more and more frustrated because it was a lot harder.” Laura wrote about a failed 5th-grade science test: “Starting then, science became my least favorite subject.” Parker reflected on her positive early science experiences and how science became more difficult for her as she advanced through her education. She concluded: “I still maintain my positive view of science that I had in elementary school, however I now see it as beyond the reach of my ability and less engaging.” Alice’s reflection in her science autobiography blog post rendered another negative judgement of desire to engage with science:

To sum things up, science is not exactly something I love at this point in my life. I know it’s important, and I know I interact with it every single day, but it just doesn’t make me jump for joy. I would much rather be reading a good book.

This qualitative finding aligns with uncertainty orientation theory that CO individuals orient away from the uncertainty and avoid active engagement in its resolution. They prefer
situations of high uncertainty, where they can avoid the discomfort caused by uncertainty. According to the theory, CO people are not motivated to engage in uncertain situations, which fits with the students’ blog reflections and general dislike for science, where such situations abound. The quality of the CO group’s social regulation of learning, in turn, suffered due to the negative SE climate that resulted from ignoring and abandoning of group members when they articulated uncertainty. Also, this group had a higher percentage of SRL in all tasks than the other two groups. Hence, both the modes and quality of social regulation of learning were impacted by the group’s avoidance of uncertainty. In the following section, I discuss the CO group’s reliance on the instructor as the authority figure for resolution of uncertainty.

**CO group: Appeals to the authority.** The CO group often responded to uncertainty by seeking help from the instructor, who they perceived as the authority figure. The group employed external help-seeking approximately three times more (i.e., 26 instances) than the other two groups (i.e., 8 instances for the UO group and 9 instances for the Mixed group), with the highest number of external help-seeking occurring in the high-uncertainty tasks (i.e., Tasks 1 and 5). They looked to the instructor for help with content knowledge (e.g., Excerpt 24, Turns 173–179), as well as for resolution of fairly minor issues that the group could have addressed internally. Excerpt 28, from Task 1, illustrates one such occasion. In this instance, the group struggled to fit the top on their bioreactor container.

*Excerpt 28. CO group: Should we ask?*

207 Alice: **Should** we ask if that's going to be okay or not?

208 Laura: Huh?

209 Alice: **Should** we ask if that's okay?

210 Laura: I think it has to be all the way in this one.
In Excerpt 28, Alice persisted in her decision to ask the instructor how to fit the two pieces together (Turns 207, 209, 211, 215, 219), although she realized that getting the help was taking some time (Turn 217). When Alice was unable to get the instructor’s attention, Laura walked away with the group’s bioreactor, without consulting with others (i.e., Turn 219). Alice and Parker shrugged off this apparent disrespect and remained sitting at the table.

In Excerpt 29, I provide another example of help-seeking for a fairly minor dilemma related to task understanding, where the group could have chosen their own interpretation of task instructions.
Excerpt 29. CO group: Well, let's ask really quickly.

221 Alice: See, I thought this had to be the landing spot. I thought these materials were for the landing spot or are they surrounding the egg?

222 Kerry: It's for the landing spot so you could-

223 Laura: Oh, it's not surrounding?

224 Kerry: Oh, I don't know actually. I assumed it was.

225 Alice: [inaudible 00:00:36]. Well, let's ask really quickly. (Alice raises her hand. To the instructor who came over to their table:) Are these materials just for the landing spot or are they going to surround our egg or both? Or either?

226 Instructor: All of the above.

227 Alice: Okay then, let's do both y'all. (Alice smiles.)

In Turn 221, Alice wondered if the task was to use the materials to create a landing spot or to protect the egg. Alice’s question exposed a difference in task understanding between Kerry and Laura (i.e., Turns 222 and 223). In Turn 225, Alice turned to the instructor to resolve the uncertainty, thus eliminating the possibility of resolving it through internal discussion. Although Alice suggested doing both (Turn 227), the group ignored this suggestion.

The group’s appeals to the external authority to resolve uncertainty and settle dilemmas were ways of orienting towards what is known and certain. The students’ reliance on external guidance, directions, and examples was also evident in their pre-task responses. For example, in her Task 3 pre-task response, Alice stated: “I feel confident I can complete this collaborative task because we first got a good example of what this should look like with the ‘Scaredy Squirrel’
book.” In her Task 5 pre-task response, Laura expressed she felt very confident in her ability to complete the task because: “We were given examples and were told explicitly what we would be doing.” For the CO group in a classroom, the teacher determined the rules, the rights, and the wrongs, hence it was the teacher’s direction they repeatedly wanted and decided to follow.

This finding is consistent with uncertainty orientation theory, which specifies that in situations of high uncertainty, CO individuals resort to heuristic processing (i.e., reliance on an authority figure) in order to avoid having to confront the uncertainty themselves (Sorrentino & Roney, 2000). The CO group’s evidenced reliance on external help-seeking, especially in high-uncertainty tasks, indicates that people of different uncertainty orientations employ learning strategies with different directionality (i.e., internal versus external) when facing uncertainty. Persistent directing of help-seeking towards an outside authority figure has the potential to erode a group’s cohesion because of implied lack of confidence in group members skills and knowledge. Also, it might contribute to the formation of maladaptive group and individual conditions for future learning situations. In the next section, I discuss the third dominant theme for the CO group: their focus on winning.

*The CO group: Focus on winning.* The CO group’s enactment of regulation of learning was characterized by the group’s focus on winning the task. The group’s competitive approach to problem-solving was not present in the baseline task, a collaborative activity, or in Task 1, the high-uncertainty task. It emerged in Task 2, which was the low-uncertainty task, and became more explicit as the level of uncertainty increased in Tasks 3 through 5. In Tasks 4 and 5, the competitiveness became manifest even within the group. The group’s goal or intent to win the task was in most cases stated by Alice, but other group members also engaged in this approach and thus jointly shaped the group’s behavior.
On two occasions in Task 2, Alice made comments about being in the middle of the pack at the start of the first whole-class debriefing, following the drop of the group’s original parachutes (i.e., Excerpt 30), and at the start of the final whole-class debriefing, following the drop of the redesigned parachutes (i.e., Excerpt 31).

*Excerpt 30. CO group: We are in the middle of the pack. We’re good.*

228 Alice: Y’all, we did pretty good.

229 Instructor: *(To the whole class:)* What did you all notice about the times here?

230 Alice: We are in the middle of the pack. We’re good.

*Excerpt 31. CO group: We are still in the middle of the pack.*

231 Instructor: *(To the whole class:)* Okay, so let’s take a look at what we got here…

232 Alice: Dang it all. We still…We are still in, like, the middle of the pack

233 Kerry: *(Kerry turns around to look at the board).* Yeah.

In Excerpt 30, Alice noticed that the group’s average time for the parachute drop put them in “the middle of the pack” and she judged that outcome to be good (i.e., Turn 230). In Excerpt 31, however, Alice’s assessment of the group’s placement in the middle became negative (i.e., Turn 232), indicating she hoped to see a better performance. Kerry was interested in the group’s final placement as well, and she agreed with Alice’s assessment that their position did not change (i.e., Turn 233). In Excerpt 32, which took place a couple of minutes later, Laura noticed an issue with one of the averages on the board, and she brought it to the group’s attention (i.e., Turn 234).
Excerpt 32. CO group: Can’t be bigger than ours.

Laura: (Laughs) Their average is not right.

Kerry: Whose?

Laura: The Blue group. (Kerry turns around to look at the board. Parker and Alice look as well.) It can’t be 2.6. Can’t be bigger than ours…

Kerry: Yeah! (Laura and Kerry chuckle.) That’s funny.

Laura: I was like, it can’t be [inaudible]

Kerry: Aha-Aha. Definitely.

In Turn 236, Laura compared their times for the three parachute drops and the corresponding average to the Blue group’s and concluded that the Blue group’s average was higher than it should be. Hence, their group had done better than the Blue group.

In Task 3, the CO group’s focus on winning became more explicit, as shown in Excerpt 33. In this excerpt, the group was waiting to conduct their egg drop experiment. They noticed that other groups had copied their idea of using the air in the bag as a cushion.

Excerpt 33. CO group: We’re going to win.

Alice: Okay. I feel like we did good.

Kerry: (Kerry looks at another group who is copying them.) Steal our idea… that was a good idea. (Parker, Kerry and Alice laugh.)

Alice: That was a great idea. That was a fantastic idea.

Kerry: Because if it falls, it bounces. (Kerry motions up and down with her hand.)

Laura: It's an original Yellow group idea. Don't steal it. The Yellow group did this. (Laura puts the cup back into the bag with both
rubber bands attached. She opens one corner of the bag and starts blowing in the air. Parker and Kerry look on. Alice is writing. Laura puts the blown-up bag with the cup in it on the table.)

245  Kerry:  Oh my God, I love that.

246  Alice:  Yes. Yeah, we're going to win.

247  Kerry:  And now we just need to drop it sideways or something so it bounces.

248  Alice:  Yeah, we are killing it. *(Everyone laughs.)* This is awesome.

In Turns 240 and 242 Alice, stated they did well and assessed their idea of adding air into the bag as “fantastic.” Kerry (Turn 241) and Laura (Turn 244), however, were concerned that the other groups had stolen their idea for their own use, thus eliminating any advantage the group might gain from it. In Turn 246, Alice declared that they would win, although neither the class nor the group discussed what would constitute a win in an egg drop experiment. The group seemed happy with Alice’s positive competitive assessment of the group’s design (i.e., Turn 248).

Although a group’s joint focus on winning typically serves to solidify that group’s cohesion, in this particular group, such instances of cohesion were only temporary (e.g., Excerpt 33). The focus on winning was also present within the group in Tasks 4 and 5, thus contributing to further degradation of the CO group climate. Excerpt 34 took place at the end of Task 4, in which Laura led the group through much of the task and the group shunned Kerry for several minutes after she was disrespectful of the group’s work efforts (i.e., Excerpt 27). In this excerpt, Alice told the others she doubted the success of their straw tower construction.
Excerpt 34. CO group: What the heck am I?

249 Alice: I'm the doubter. Every group needs a doubter to push you to be better.

250 Parker: Because you're the skeptic.

251 Alice: I'm the skeptic, [To Laura:] you're the visionary....

252 Kerry: What the heck am I?

253 Alice: The strong hand of support. *(Kerry laughs out loud.)*

254 Kerry: Hey, I came up with the air in the bag idea.

255 Alice: You did. That was awesome.

256 Laura: You did.

In Turn 249, Alice presented her doubts about the group’s design as a positive way to participate by challenging the group to do better. Parker, who had also made a limited contribution in this task, was supportive of Alice (Turn 250). Alice then proceeded to mend the relationship with Laura, calling her a visionary (i.e., Turn 251). The evaluations of the group members’ roles took a competitive and testy tone with Kerry’s question in Turn 252. Alice’s response (i.e., Turn 253) emphasized Kerry’s supporting role in the task after the group let her back into the conversation. Alice’s response, perhaps inadvertently, placed Kerry at a lesser social standing within the group than Laura. Kerry was not satisfied with this evaluation and, in Turn 254, she reminded the group that she had made the key contribution in Task 3. Alice and Laura both agreed (Turns 255 and 256).

In Task 5, the competitive spirit was evident even during the card game that was a part of one of the puzzles. The point of the game was for the group to play through all the cards and discover the order in which decomposers act on the organic material, thus there were no
individual winners in the game. In Excerpt 35, Laura used up all of her cards and thought that meant she had won the game.

Excerpt 35. CO group: I won.

257 Laura: I'm done. I won. (Alice laughs.)

258 Kerry: If you have no cards ... oh wait. (Kerry looks at the instructions.)

259 Laura: You have no cards, I win?

260 Kerry: End of turn, draw back up to three cards.

261 Laura: Oh. (Laura looks disappointed.)

In this task, Alice shared her goal of winning with the group: “I want to solve it first.” However, despite the group’s efforts, they were not the first group to solve the escape room. In Excerpt 36, the Mixed group cheered loudly after they had solved the escape room.

Excerpt 36. CO group: Dang it. Hurry guys.

262 Mixed group: (Loud cheers and laughter)

263 Alice: [To the Mixed group:] Did y'all solve it? Are y'all broke out?

264 Student: Yes, we broke out.

265 Alice: Dang it. Hurry guys. (Laura laughs out loud.)

In Turns 263 and 265, Alice confirmed the Mixed group had broken out of the escape room. In Turn 265, Alice acknowledged that their own group fell short of their initial goal to finish first (i.e., “Dang it”) and urged the group to hurry up so that they could finish second. With this statement, Alice implicitly modified the group’s goal from finishing first to finishing second. The group achieved this secondary goal and shared high-fives at the end of the task to celebrate.
The CO group members’ blog posts supported the finding about the group’s competitive drive. In their escape room blog posts, the students mentioned their focus on completing the escape room as fast as possible, admitting it detracted attention from content learning. Kerry wrote: “It is hard to pay attention to learning about composting when I feel like I am just trying to solve the puzzle as quickly as possible.” In her blog, Alice stated: “Sometimes I was just scanning the documents trying to find the answer quick instead of actually taking the information in and making connections in my mind.” Laura’s blog post about project-based learning contained references to leading the group: “I think student leadership is super important. During project-based learning, students have the opportunity to lead their group in the experiment.” Combined with the groups’ blog posts, which I described in my findings about the role of social comparison in Research Question one, these posts revealed an awareness of and focus on the group members’ standing as compared to others both within and outside the group.

Whereas uncertainty orientation theory does not specifically address how UO and CO individuals perceive winning or the importance they might assign to it, the theorists posited that for the CO individuals their groups serve as a source of shared reality and self-verification (Sorrentino & Roney, 2000). Thus, it is reasonable that, as the task level of uncertainty increased, the CO group’s focus on winning became more apparent, acting as a way for this group to engage in self-verification. As a reminder, for the CO group, evaluating through social comparison, which accounted for 25% of group evaluating, was more prominent than in the other two groups. In contrast, the UO group dedicated only around 5% of their evaluating to the evaluating through social comparison and the Mixed group had no instances of it. This qualitative finding about the CO group’s focus on winning is important because it points to a
difference in goal and standard setting between groups of different uncertainty orientations, which in turn shapes intragroup and intergroup dynamics and social regulation of learning.

Briefly, of the three themes that characterize the CO group’s regulation of learning, the themes avoidance of uncertainty and appeals to the external authority to resolve it align well with uncertainty orientation theorists’ descriptions of COs behaviors (e.g., Brouwers & Sorrentino, 1993; Roney & Sorrentino, 1995a; Sorrentino et al., 1988). The third dominant theme, the CO group’s focus on winning, illuminates a dimension of the CO group that uncertainty orientation theorists did not specifically discuss in their predictions. However, the group’s focus on winning fits with the proposition that CO individuals use groups as a source of self-verification and shared reality (Li et al., 2017; Sorrentino & Roney, 2000), so the group’s shared focus on winning might have served as a heuristic to achieve these goals and set the group apart from others.

The qualitative themes that describe the CO group’s social regulation of learning, hence, suggest a different focus in standards and goal setting than observed in the UO group. The CO group’s avoidance of uncertainty led to a lower quality SSRL and a higher number of SRL instances than observed in the other two groups. The finding about persistent reliance on external authority to resolve the uncertainty through external help-seeking provides new information about which groups might be resorting to different strategies and why. Winning as a part of a group’s standards and goals shaped the groups’ monitoring and evaluating processing, funneling them through social comparison towards superficial performance orientation. Next, I describe the main qualitative themes for the Mixed group.

**Mixed group: Untroubled by uncertainty.** The Mixed group was unique in their ability to remain untroubled by the encountered uncertainty, whether they left it unresolved by not
pursuing it or resolved it through group discussion. In the UO group, uncertainty served as a stimulus to actively pursue its resolution and, in the CO group, as a stimulus to engage in avoidance and orienting towards certainty. However, the Mixed group was often comfortable with leaving the identified uncertainty acknowledged but unresolved. Examples that I introduce in this section come from tasks of high and moderate uncertainty. In Task 2, the low-uncertainty task, and Task 5, in which the uncertainty related to each puzzle had to be resolved if the group was to move through the task, I found no examples of unresolved uncertainty. In Excerpt 37, from Task 1, the high-uncertainty task, Stella and Kate reviewed task instructions while they were waiting on Tom to come back from the store with the group’s second bottle to assemble the bioreactor.

Excerpt 37. Mixed group: Why would we not just cut there?

266 Stella: I'm a little **confused**, why we do all of this to make it into this...

267 Kate: Right.

268 Stella: …Instead of just, putting it in a bottle.

269 Kate: Right, why **would** we not just cut there (Kate points to a spot on the instructions sheet) and put...

270 Stella: Where?

271 Kate: Right.

272 Stella: But **maybe I don't understand** what's happening.

In Turn 266, Stella expressed confusion about the need for two bottles to assemble the bioreactor. Kate agreed with Stella (Turns 267, 269, and 271), pointing out that perhaps it would be possible to build the bioreactor using just one bottle. Stella then raised a possibility that she might be misunderstanding the task instructions (i.e., Turn 272). Kate and Stella did not pursue
this line of conversation any further, thus leaving the uncertainty identified but unresolved. Instead, they focused on following the instructions to cover the top of the bottle with a piece of the stocking.

The group discussed this identified lack of understanding again in Excerpt 38, which took place after Tom came back with the second bottle. Stella updated Tom on the current situation with the group’s bioreactor build.

*Excerpt 38. Mixed group: We will see.*

273 Stella: **We were a little confused** why we had two bottles instead of just one bottle, but we **will** see.

274 Kate: Yeah.

275 Stella: Okay.

276 Tom: Alright. *(Tom manages to put the rubber band on top of the bottle to hold the stocking in place.)*

277 Kate: Good deal. So, now A [part A of the bioreactor] goes in...

In Turn 273, Stella told Tom about their confusion regarding the need for two bottles and followed it up with a statement that they “will see.” Stella’s statement was non-specific, but all three group members seemed unbothered by this open-endedness, as evident by their statements in Turns 274–277. Once again, the group oriented towards reading and following the instructions to make the cuts in the bottles and put the bioreactor together. In Excerpt 39, from Task 4, the more difficult of the two medium-uncertainty tasks, Stella and Tom finished building their straw tower construction and noticed that their construction was not stable.

*Excerpt 39. Mixed group: It’s going to lean the other way?*
In Turn 278, Stella explored a possibility that maybe just one side of their construction was unstable and proposed putting the ball more towards the other side. In Turns 279–282, Tom and Stella then jointly came to a conclusion that placing the ball on the other side would cause their construction to lean the other way. Tom was unsure of why the pillars of their construction did not stand straight (i.e., Turn 283), and Stella stated she did not know either (i.e., Turn 284). The students left the issue of the stability of their construction unresolved and made only a superficial and unrelated change to their design prior to the final test. The group’s ability to articulate uncertainty, yet leave it unresolved without ignoring group members contributed to the impression that the group was even-keeled, laid-back, and untroubled by uncertainty, regardless of what was happening. Their interactions remained positive and cordial through all tasks; the Mixed group had the least number of negative SE codes of the three groups, further supporting the interpretation that they were untroubled by uncertainty.
Similar to their classroom interaction, in their blog posts, the students identified certain issues but left them open-ended, offering no resolutions. Tom ended his blog about the construction of the bioreactor with a statement that the task would be exciting for 1st-graders and expressed the following doubt: “but I'm not 100% sure the gathering of data each week would be as exciting for them, especially if their reactors are "changing" at the rate our group’s reactor is.” In two of her blogs, Stella identified a concern about differences in her students’ pre-existing knowledge about composting but both times stopped short of pursuing this train of thought any further or offering a potential solution. For example, in her blog about the bioreactor task, she wrote: “If I did this activity with my class, I think students would have varied understandings. As mentioned in my earlier post, some of my students come from homes that compost and would be more familiar with the process.” Thus, the students’ blogs provided additional evidence that students in this group were comfortable with articulating but not necessarily resolving uncertainty every time. Quantitative data showed that the Mixed group engaged in controlling less than the other groups, so it was possible that the group’s lack of controlling was, in part, due to their stopping short of resolving the uncertainty. The uncertainty orientation researchers typically excluded moderates from their studies and offered no expectations about them in the theory because their behaviors could not be predicted (e.g., Hodson & Sorrentino, 1999, 2003; Szeto et al., 2011). Hence, this and other findings about the Mixed group contribute new insights into how uncertainty orientation of the group members might create unique group conditions and combine with task conditions to shape the group’s social regulation of learning. In the next section, I discuss the Mixed group’s focus on task parameters.

**Mixed group: Focus on task parameters.** The Mixed group’s regulation of learning was also characterized by their persistent focus on adherence to the task parameters. For example, in
the baseline task, the group internally discussed the TerraCycle category, but, as mentioned previously, they did not share their discussion with the rest of the class, neither during their reporting out, nor when the UO group contributed TerraCycle as a new category for the whole class. In contrast, the UO group internally added TerraCycle as the category (see Excerpt 19) and then Emma invited Julie to share it with the whole class during the reporting out. As a result of the UO group’s sharing, the instructor added TerraCycling as a fifth category of waste disposal to the four original categories (reuse, recycle, compost, and dispose). Thus, by not venturing into TerraCycle discussions beyond the confines of the group, the Mixed group adhered to the task parameter of four instructor-specified categories.

In Excerpt 40, from Task 3, the Mixed group selected the tallest group member (i.e., Stella) to do their egg drop. In her instructions to the class, the instructor explained the egg drop is typically done from a second story window. Because the building where the class was held was a single-story building, the instructor told the groups to stand on a chair or table to do their egg drop. The Mixed group, thus, adhered to the task parameters (i.e., dropping the egg from the tallest possible point) as best they could by having Stella climb on the table.

Excerpt 40. Mixed group: Who’s the tallest?

285 Jane: Okay, who's the tallest? Or does it not matter?
286 Tom: Not me. I'm 5'7".
287 Stella: Probably me. And I have tall shoes on.
288 Tom: Yeah, I think it might be you.
289 Stella: All right. I'm scared to get up here.
In Excerpt 41, from Task 4, the group discussed the task constraints of using all the straws and not running out of tape when building the straw tower. Through the discussion, Tom and Stella came up with the plan to meet both constraints.

Excerpt 41. Mixed group: Scared we’re going to run out of tape.

Tom  Scared we're going to run out of...

Stella:  Of tape?

Tom:  Tape

Stella  I know, we can't undo it... I guess we can. All right. And then maybe we do one across this way. I have no idea how we're going to use all of these. I feel like this is.... that's solid. (Stella pushes down on their construction with her palms.)

Tom:  All right.

Stella:  Maybe we do a bunch across? I don't know how we would do tape-wise. (Stella and Tom both glance at the piece of remaining tape.)

Tom:  Yeah.

Stella:  But if we could do that, that would be just... to hold the weight. (Stella takes a bunch of straws, puts them neatly next to each other, and holds them close to the top of their construction, representing a platform.)

Tom:  I wonder... (Tom takes two straws and starts attaching them together) this may be the worst idea in the world.

Stella:  I mean, I've had plenty of bad ideas.
In Turn 290 and 292, Tom shared his concern about running out of tape and, in Turn 293, Stella raised a concern about using all the straws, so the students were attentive to both constraints at the same time. Tom then hesitantly offered a solution (i.e., Turn 298). With Stella’s encouragement (i.e., Turn 299), he proceeded to demonstrate his idea (i.e., Turn 300 and 302) about attaching straws to each other and wrapping them around the base construction in a double layer, thus using all the straws. Stella enthusiastically supported this idea (i.e., Turns 301 and 303). Finally, in Turn 304, Tom pointed out they could only use tape to fix the ends, hence limiting their reliance on tape in their design. In contrast, the UO group in Task 4 discussed using all the straws on several occasions, but ultimately disregarded the constraint so that they could carry out their plan to build a hammock-like construction.

Members of the Mixed group also discussed parameters that might impact the composting speed in their blog posts. For example, in his blog post about the group’s bioreactor, Tom wrote:

At the moment, we are struggling a bit as our materials aren't really breaking down very quickly. The EPA states on their website that greens and browns should be in equal proportion, and I don't believe we have equal proportions at the moment.

Kate reflected on the class’s visit to the community garden: “Finally, based on the info that the garden manager gave us, the size and scale of one’s own composting endeavor typically correlate with the level of difficulty/work load.” Thus, for this group, task parameters were an
important part of the standards against which they monitored their task progress. The Mixed group’s standards aligned with the standards specified by the course instructor. In contrast, the UO group prioritized their own standards and their goal of achieving creative solutions over adherence to the task parameters set by the instructor. This finding indicates that the social regulation of learning that unfolded in groups of different uncertainty orientations was steered by different foci, some more conducive to the intended learning goals than others. The next qualitative theme, skillful use of learning strategies, complemented the Mixed group’s focus on task parameters.

**The Mixed group: Skillful use of learning strategies.** Over the course of five tasks, the Mixed group’s regulation of learning was characterized by the effective and adaptive use of the learning strategies, as well as the consequential modification of regulation targets to produce the desired outcomes (e.g., monitoring of the environment in Task 5). Examination of the top four learning strategy codes (i.e., reading, taking notes [TN], external help-seeking [HSE], and preliminary testing [PT]), revealed that, with the exception of external help-seeking, the Mixed group used them more than the other groups (Table 4.16).
Table 4.16

**Most Prominent Learning Strategies**

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Qualitative analysis showed that the key difference was which learning strategies were used, how and when the group used them, and how and when they modified targets of their regulation. For example, in Tasks 2 through 4, the Mixed group utilized preliminary testing as a proof of concept or to test the design already under implementation. The group’s use of the preliminary testing strategy is illustrated in Excerpt 8 from Task 3, Turn 51, when Jane dropped the group’s the air-filled bag as a preliminary test of their finished product. In Tasks 1 and 5, where preliminary testing was not as applicable, this group employed reading and taking notes.
more than the other two groups. In Task 5, it was the group’s unparalleled close reading of the
instructions and relying on the directions and taking notes at the right moments, that set them
apart and enabled them to complete the escape room faster than other groups. Excerpt 42, from
Task 5, in which the group had just started a new puzzle and had to play a mini-card game as a
part of it, illustrates how the group used reading.

Excerpt 42. Mixed group: Play a material first.

305 Kate: Yay! All right. *(Reads:)* “On your turn you may play as many of
one type of card as you have in your hand.” So, I *guess* there's...

306 Jane: *(Points to one of the papers on the table.)* So, it goes material,
plant/animal matter to be broken down, so you need...

307 Kate: What the...

308 Jane: I *guess* you have to play a material first, and then you play the
bacteria.

309 Kate: Mmm, yeah.

310 Jane: Or, if it's a complex...

311 Kate: *(Reads:)* “Enzymes you can place on a stack with a material and
bacteria card. Tear the material card into the complex molecules.

Yes, actually tear the card into strips."

312 Tom: Okay.

313 Stella: Okay.

In Turn 305, Kate started reading the instructions for the decomposer mini-game to the
group. In Turns 306 and 308, Jane then used the information provided on one additional sheet to
resolve the uncertainty about the order in which the cards should be played (i.e., the material
card, the bacteria, then the enzymes). Kate then continued reading the instructions for the game (i.e., Turn 311), adding to what Jane shared with the group. Tom and Stella (Turns 312 and 313) acknowledged they understood the instructions. Thus, in the first reading of the instructions, the group established an understanding of the order of cards, so they were able to start the game quickly and correctly. In contrast, as shown in Excerpt 43, the UO group was immediately overwhelmed by the detailed card game instructions and read only the beginning of the instructions prior to starting the game.

Excerpt 43. UO group: There’s a lot of words here.

314 Emma: “On your turn you may play as many of one type of card as you have in your hand.” Oh, there's a lot of words here. (Emma laughs.)

315 Julie: Oh, my gosh.

316 Emma: Okay, guys. “As many of one type of...” Okay. I have two of these (She separates two of her cards from the rest.) so “enzymes two”, “place on a stack where the material...” (She looks at the instructions.) Huh? (She looks at the group, stomped.)

317 Sarah: All right, hang on. (Sarah leans in to see the instructions.) All right. (Reads:) “So on your turn you may play as many as one type of cards as you have in your hand. Material…play anywhere to start.” So, we need to start a new stack.

In Turn 314, Emma started reading, but was overwhelmed by the perceived length of the instructions. Julie (Turn 315) also had a negative reaction to the length of the text. In Turn 316, Emma attempted to begin the game play while she was still skimming the instructions, reading
only some parts out loud (i.e., so “enzymes two,” “place on a stack where the material”).

However, she was confused and was not able to start the play. In Turn 317, Sarah tried to help. Sarah’s reading was repetitious, fragmented, and short-lived, focusing just on starting the game. The UO group rushed to begin the game with only limited understanding and, in turn, struggled with the order of cards and general game rules.

When they were unsure of how to proceed, the Mixed group kept referring back to the instructions as exemplified in Excerpt 44 and did so more than the other groups. In Excerpt 44, the group worked to resolve uncertainty about what to do with the strips of the torn material cards.

*Excerpt 44. Mixed group: They have to be simple.*

318 Jane: So, what do we do with those strips?

319 Stella: I don't know.

320 Kate: Yeah, I don't...I don't really feel like this is part of... (Kate and Stella laugh.)

321 Tom: All right.

322 Stella: And, we've still got all these to go. (Stella touches a pile of unopened puzzle envelopes in the box next to her.)

323 Kate: (Reads:) “Add the simple molecules to the nutrients pile.”

324 Stella: Okay, so we make a pile of them? Yes, nutrients. (Stella moves torn strips of paper into a single pile.)

325 Kate: Uh-huh (affirmative). Enzymes two-

326 Tom: But they have to be simple. We have to have broken them down into simple molecules. (Tom points to the instructions sheet.)
Jane: Oh, so it needs to be further broken down.

Stella: Oh, they have to be broken again? Well, I have another bacteria.

Kate: That's what we need the simple two enzyme, or the enzyme two for.

Stella: Oh!

Tom: I have an enzyme two.

Stella: Okay.

Jane: Oh, to break them down…

In Turns 318 through 320, the group identified a lack of understanding about how to proceed with the torn card strips. In Turns 320 and 322, Kate and Stella seemed temporarily discouraged by the sheer number of puzzles still ahead of them. However, Kate quickly refocused the group by reading another line from the instructions (Turn 323), which explained what to do with the simple molecules. In Turn 324, Stella took this explanation to mean that the strips of paper represented simple molecules and she moved them into a pile. Tom, however, corrected her misunderstanding by pointing back to the instructions to remind the group the strips represented complex molecules and needed to be broken down further. Both Jane (Turn 327) and Stella (Turn 328) reacted positively to this explanation. When Stella offered another bacteria card to break down complex molecules (Turn 328), Kate realized that there was also a lack of understanding about how to break down complex molecules, so she reminded the group that they needed an enzyme two card for that (Turn 329). Once they understood the card order, the group smoothly proceeded with the card game.

The Mixed group also engaged in note-taking at key moments in Task 5. In Excerpt 45, the group used lists of ingredients for calculating C:N ratios, but they were not sure what the C:N
ratio was for or how to connect it to the numbers on the puzzle lock (i.e., 52, 78, 97). Tom previously went and got a pen from the neighboring classroom because the group was struggling with calculations.

Excerpt 45. Mixed group: C:N is 32.

Tom: I don't understand.

Jane: 78...

Stella: Oh, maybe it would be the C:N if something weighed 78.

Jane: Oh, wait, this is batch number 97, 78...52. (Jane points to numbers in the upper right-hand corner on three different pieces of paper.)


Stella: Okay.

Tom: Okay, so 78, 52... So, this one, what's the... (Tom is ready to write down the number calculated for the first batch.)

Jane: C:N is 32? Is that what you're looking for?

Stella: Yeah.

Tom: Yeah.

Jane: 32.

Tom: 32- (Tom writes down the number.)

Stella: For the batch.

Tom: ...so we need to figure out the batch for each of these.

In Turn 334, Tom expressed a lack of understanding about what the group was doing. Stella offered a hypothesis that maybe they were looking for a C:N ratio for something that weighed 78, but Jane (i.e., Turn 337) found that each list of ingredients had a number in the
upper right-hand corner. Using this new discovery, Tom realized that the ratio they just calculated was for the first batch (Turn 340). In Turn 345, he wrote down the number for the first batch, and, in Turn 347, he provided the group with the direction for the next steps (i.e., calculate the C:N ratio for each batch). As the group continued to work on the calculations, Tom wrote down ratios for each batch, thus enabling the group to simply enter the calculated ratios into the computer and solve the code. In contrast, the other groups tried to assign a group member to memorize the ratio numbers. Memorization as a strategy proved to be difficult because each C:N ratio calculation involved different weights of many different ingredients, thus inducing a demanding cognitive load and interfering with the students’ ability to recall the exact numbers they needed.

The Mixed group used external help-seeking only twice in this task, but both times at critical junctures. The first time they briefly spoke to the course instructor who provided indirect assistance after which the group quickly discerned the right course of action for one of the early puzzles. In Excerpt 46, after the group’s multiple failures to solve the last puzzle in the escape room, Kate decided to ask for help from the teaching assistant.

_Excerpt 46. Mixed group: We need another clue._

348 Kate: *(Stella dictates the code numbers and Kate types them into the computer.)* Zero. No. Damn! *(Loud sigh.)*

349 Jane: What?!

350 Kate: TA, we need another clue.

351 Teaching *(The teaching assistant comes over to their table.)* A clue. All

Assistant: right.

352 Stella: We’ve been [crosstalk].
Kate: The colors are really getting us.

Stella: We tried mixing them.

Teaching Assistant: Okay, so where do you think those are going to go?

In Excerpt 46, as frustration over the repeated failures mounted (Turns 348 and 349), Kate independently made a decision to ask the teaching assistant for help (Turn 350). In this case, both the external help-seeking and individual decision-making prevented further futile attempts and preserved the students’ motivation, which as Kate indicated in Turn 353, was starting to suffer. The teaching assistant engaged in a 50-second conversation with the group, helping them develop an understanding of how to combine puzzle clues and move forward.

The escape room used in Task 5 included multiple puzzle envelopes, locks, sets of instructions, a deck of paper cards, and multiple small round tokens, so the potential for the groups to become confused and focus on wrong sets of clues was significant. After commenting several times on how many papers there were on the table, the Mixed group engaged in monitoring and control of the environment for the first time in the series of five tasks. One such instance is shown in Excerpt 47.

Excerpt 47. Mixed group: Let’s get rid of this.

Tom: Oh, so this is all the material that we need for the temperature timeline. *(Jane puts the two sheets from the previous puzzle off to the side.)*

Stella: That makes more sense. Okay.

Jane: So, here's the temperature timeline.
In Turn 356 through 358, Tom, Stella, and Jane started setting up for the next puzzle. Tom urged the group to remove all of the papers used in the previous puzzle (i.e., Turn 359). Jane and Tom then worked together to clear the middle of the table, so that it could be used for the next round of clues. In Turn 361, Stella presented the clues for the next puzzle to the group as she laid them out across the table. The group kept all used pieces in a single pile off to the side and kept only the current puzzle materials in the middle of the table where all group members could see them.

Members of the Mixed group also wrote about their perceptions of the environment in their escape room blog posts. For example, Kate stated: “One thing that I did not like was it was a lot of different pieces of paper, and it seemed very difficult to ‘reset’ the box for another use.”
Similarly, Jane wrote: “Something that I did not like was the amount of papers and materials, this felt very overwhelming because I did not know what we needed and didn't need for each step.”

By recognizing and regulating a critical target (i.e., the environment), the group was able to focus on and keep track of the clues relevant for the current puzzle. Although the other two groups attempted to monitor and control their environment as well, they were not as systematic as the Mixed group. Due to the insufficient management of the environment, both the UO and the CO group ended up temporarily losing one of the puzzle pieces on the floor, a mistake they didn’t discover until the teaching assistant alerted them to it. Hence, the progress of the UO and CO groups was thwarted because they failed to monitor and control the environment effectively and consistently.

**Summary for Research Question 2.** With Research Question 2, I investigated how preservice teachers' enactment of social regulation during collaborative learning differed with respect to the uncertainty orientation of the group and the degree of situational uncertainty in the task. I found differences in two important factors related to the groups’ social regulation of learning: on-task engagement and SE climate. Across all tasks, I found that the UO group, on average, spent the most time on-task and the least amount of time off-task, whereas the CO group spent the least amount of time on-task and the most time off-task. This finding is consistent with predictions from uncertainty orientations theorists that the UO groups would be more engaged in situations requiring active exploration than the CO groups (Brouwers & Sorrentino, 1993; Sorrentino et al., 1984). Another notable finding was that the amount of time the CO group spent off-task kept increasing from Task 1 to Task 4 before going to zero in Task 5. This finding seems to indicate that the CO group was influenced by the task openness in Tasks 1 through 4, leading to increased disengagement from the task. The sequential structure of Task
5, which, according to uncertainty orientation theory, is more suitable for people who are CO (Huber, 2003; Huber et al., 1992), helped the CO group return to full task engagement. In addition to on-task engagement, another important factor that shapes a group’s regulation of learning is the group’s SE climate. The CO group dynamics were characterized by an overall negative SE climate. Conversely, the UO and Mixed groups had positive SE group climate. Interestingly, the groups with positive SE climate controlled their emotions, but the CO group did not. As the task uncertainty level increased, the CO group cohesion deteriorated, and negative SE interactions, which were left unaddressed, culminated in Task 4, the medium-uncertainty task. As I discussed previously, the CO group’s interactions resembled the other two groups in Task 5.

Through the qualitative analysis, I discerned three unique salient themes for each group that characterized their social regulation of learning. For the UO group, the three key themes were their active pursuit of uncertainty, reliance on support within the group, and focus on creative solutions. The group’s active approach to resolving uncertainty was evident in the persistent action-taking to address uncertainty and obtain new information. Across the five tasks, the UO group engaged in planning less than the other two groups. As the group worked to address uncertainties identified by individual members, they relied on the group’s internal resources to support each other. They respectfully asked for and offered help to each other, thus maintaining and fostering good group cohesion. The UO group’s regulation of learning was driven by the group’s enthusiastic focus on achieving creative solutions, even if that meant slow task progress or disregarding of the task parameters. The group’s overarching focus on creative solutions was reflected in the targets of their regulative macro-processing. For example, the quantitative finding that the UO group dedicated a greater percentage of their monitoring to the
monitoring of task plans than the CO and Mixed groups aligned with the UO group’s tendency to capitalize on open task structure and pursue non-standard, creative but often more complex task solutions that required greater plan monitoring to execute. The group’s focus on creative problem-solving was evident from the baseline task through Task 4. Task 5, with the linear escape room design, presented a disruption to the UO group’s typical approach to problem-solving and regulation of learning. Thus, the group struggled in this task more than the other groups and was the last group to complete the escape room.

For the CO group, the three distinguishing qualitative themes were avoidance of uncertainty, reliance on appeals to the authority to resolve uncertainty, and focus on winning. Members of the CO group often avoided uncertainty by withdrawing from situations in which it arose and from engagement with the group members who articulated it. Through quantitative investigation of regulative modes by group by task, I also illuminated a stable pattern of greater reliance on SRL in the CO group across the five tasks than in the UO and Mixed groups. Members of the CO group often looked to the class instructor for help resolving task dilemmas, evoking a strategy of external help-seeking more than the other two groups, especially in the two high-uncertainty tasks, Tasks 1 and 5. The CO group’s regulation of learning was characterized by the competitive dynamics and focus on winning that emerged and became more pronounced as the task level of uncertainty increased in Tasks 3 through 5. In Tasks 4 and 5, the competitiveness became manifest even within the group. The CO group’s focus on winning contributed to the group’s greater use of social comparison in monitoring and evaluating than was observed for the other two groups.

For the Mixed group, idiosyncratic themes were the theme of being untroubled by uncertainty, focus on task parameters, and skillful use of learning strategies. The theme of being
untroubled by the uncertainty refers to the group’s ability to sustain stable group dynamics and task engagement whether they articulated uncertainty but left it unresolved, or whether they jointly worked on addressing it. Whereas the other two groups either actively engaged with the uncertainty (i.e., the UO group) or attempted to avoid it (i.e., the CO group), the Mixed group was comfortable with identifying and articulating uncertainty and then leaving it open-ended without disturbing their positive group climate and mutual respect. Quantitative analysis supported this qualitative finding; the Mixed group engaged in less controlling than the other two groups. The Mixed group also adhered to the task parameters, indicating that they considered them to be a critical part of the task standards that needed to be monitored. The group’s focus on task parameters aligned with the quantitative finding that this group engaged in monitoring of content understanding more than the other two groups. Another salient theme in the Mixed group’s regulation of learning was their adaptive use of learning strategies and modification of regulation targets to produce the desired outcomes (e.g., implementing monitoring of environment in Task 5). They used the top four learning strategies more than the other two groups and did so more skillfully and at opportune moments in the tasks. Their approach made the greatest difference in Task 5, in which they were the first group to complete the escape room.

In summary, differences in the groups’ uncertainty orientation and in the uncertainty levels of five tasks worked synergistically to shape the groups’ qualitatively different social regulation of learning. Differences in the groups’ social regulation of learning were evidenced by the quantitative analysis of the coding data and qualitative analysis of the video-observations. These findings are important because they offer a first look into how groups of different uncertainty orientations regulate their learning in response to tasks of different uncertainty levels.
in a real-life science methods classroom. I further contextualize and discuss my findings as well as their implications in the next section.
CHAPTER 5: DISCUSSION

The critical socioscientific issues of the 21st century, such as climate change, global pandemics, and water and food shortages, are characterized by inherent uncertainty. Addressing those issues will require robust scientific literacy, which includes the ability to grapple with uncertainty, as well the ability to engage in sustained and productive collaborative work. Thus, people need to develop scientific knowledge and multifaceted competencies, including collaboration, communication, critical thinking, and creativity (National Education Association, n.d.). To foster development of such versatile knowledge and skills in alignment with the latest science education standards, educators strive to engage students in scientific practices, which are social and collaborative in nature (NGSS Lead States, 2013).

An additional level of complexity in training learners to effectively engage with uncertainty stems from individual differences in dealing with uncertainty. Namely, findings from social psychology have indicated people vary in how they deal with the uncertainty inherent to science and collaboration (Sorrentino & Roney, 2000). The different propensities for coping with uncertainty are referred to as uncertainty orientations, with UO individuals being on one end of the continuum, CO individuals on the other end, and individuals of moderate uncertainty orientations in the middle (Sorrentino & Roney, 2000). UO individuals tend to approach uncertainty, engage in active exploration, and think deeply to resolve it. In contrast, CO people focus on retaining certainty and clarity of their present worldview and strive to avoid uncertainty, seeking out unambiguous situations. Behaviors of individuals of moderate uncertainty
orientations tend to be unpredictable, so social psychologists have typically excluded them from their studies (Sorrentino & Roney, 2000). Because solving most science problems necessitates collaborative efforts, K–12 educators have focused on affording their students opportunities to engage in collaborative problem-solving. However, it is reasonable to expect that group members with different uncertainty orientations engaged in collaborative science inquiry will experience and deal with uncertainty in different ways. Moreover, science tasks can vary in the degree of uncertainty they pose. Therefore, it is important to consider how uncertainty levels in science and design tasks interact with individual differences in uncertainty orientations to contribute to the challenges (e.g., motivational, socio-emotional, cognitive) that students face when working collaboratively.

To overcome these challenges encountered during collaborative work, group members need to skillfully and collectively plan, monitor, control, and evaluate their learning. Researchers define these processes as the social regulation of learning (Hadwin et al., 2018). Thus far, researchers on social regulation of learning have investigated the general challenges small groups experience, their subsequent adaptive responses, and the emergence of regulation of learning (Hadwin et al., 2018). However, less is known about how group members’ individual differences, such as uncertainty orientations, might shape collaborative learning and subsequent social regulation of learning. Specifically, researchers have not investigated the role of uncertainty and individual differences as stimuli for social regulation of learning in collaborative groups. With my multimethod study, I aimed to address this identified gap in the research. I drew on science education, social psychology, and social regulation of learning literature to develop a holistic and contextualized understanding of how scientific task uncertainty interacts with
First, to determine preservice teachers’ typical ways of dealing with uncertainty, I measured their uncertainty orientation. Then, I assigned participants into four-person collaborative groups based on their uncertainty orientations with an aim of ensuring variability within and among groups. I purposefully selected three groups for video observation: a UO group, a CO group, and a Mixed group. Next, collaborative groups engaged in a non-inquiry collaborative task to establish a baseline of group dynamics, followed by a series of five inquiry tasks of varying levels of uncertainty that took place over the course of the semester. I operationalized different levels of inquiry task uncertainty as levels of task structure (i.e., how well- or ill-structured they were; Shin et al., 2003). My primary data source was video recordings of the groups’ collaborative sessions. I used participants’ prospective pre-task responses, retrospective reflections (i.e., blog posts), and observational field notes for my data triangulation. For qualitative data analysis, I relied on sociocultural discourse analysis (Mercer, 2004) as a primary method of interpreting and understanding the groups’ regulation of learning.

I asked the following two research questions:

- **Research Question 1:** How do collaborative groups of preservice elementary school teachers socially regulate their learning when they encounter scientific uncertainty inherent in the task?

- **Research Question 2:** How does preservice elementary school teachers’ enactment of social regulation of learning during collaborative inquiry vary with respect to the degree of situational uncertainty in the task and the uncertainty orientation of the group?

In the following sections, I discuss the main findings for each of the research questions.
Discussion of Findings for Research Question 1

In response to Research Question 1, I found that there were similarities in how groups of preservice teachers regulated their learning when encountering scientific uncertainty. Three qualitative themes that were similar across all three groups were: collaborative approach to task completion, regulatory processing primarily focused on task, and use of social comparison in regulation of learning.

Collaborative work, with differences in the quality of social regulation. The finding that all of the groups primarily relied on collaborative work aligns with the existing literature (e.g., Määttä, Järvenoja, & Järvelä, 2012) but also expands upon it by explicating that individual differences in uncertainty orientation influence the frequency and quality of social regulation of learning. Although all three groups, in general, worked collaboratively to navigate through the uncertainties, I found that the CO group had a lower percentage of SSRL than the other two groups. Also, when the CO group engaged in SSRL, it was of lower quality than that observed in the other two groups due to subtle but persistent acts of disrespect and frequent ignoring of group members’ statements articulating uncertainty. This finding aligns with findings from Rogat and Linnenbrink-Garcia (2011, 2013), who also found that low quality SSRL and numerous negative SE interactions overlap.

Interestingly, the retrospective reflective blog posts of the CO group members reflected only positive aspects of their teamwork and reliance on their peers. Social psychologists studying uncertainty orientations (e.g., Sorrentino et al., 1988) have relied on dual processing theory to explain this phenomenon. Dual processing theory (Kahneman, 2013; Tversky & Kahneman, 1974) specifies that there are two modes of thinking: slow, effortful thinking and fast, automated (i.e., heuristic) processing. My finding about the CO group members not reporting negative
aspects of their group interaction is consistent with findings from social psychology (Huber et al., 1992; Sorrentino et al., 1995) that CO individuals tend to resort to using heuristics and rely on fast processing when responding to retrospective measures that require recall of actual situations (e.g., “I’m supposed to trust my team members”), which in turn resulted in non-reporting of issues within the group. Methodologically, my finding is significant for researchers on social regulation of learning and SRL relying on retrospective measures in their studies, because it illuminates how CO individuals’ responses might be inadvertently distorted by their reliance on fast processing (i.e., using the relevant heuristic), rather than on slow processing and analysis of the actual group dynamics. Consistent with uncertainty orientation theory (e.g., Hodson & Sorrentino, 1997; Sorrentino & Roney, 2000), I also found that the CO group used heuristic processing when they repeatedly relied on the authority figure (i.e., the course instructor) to resolve uncertainty instead of tackling it on their own. For practitioners, this finding suggests that groups with lower quality social regulation of learning might need to be supported in a two-step approach: first, to move away from heuristics, and then, second, to productively address the identified problems. For example, one way help CO students recognize maladaptive heuristic processing and help them engage in a more effective manner might be for the class to jointly discuss and analyze hypothetical situations that illustrate collaborative group engagements of high and low quality with examples of heuristic processing, focusing on regulative questions group members should ask themselves and others to facilitate improvement (e.g., “Do I ask my peers follow-up questions when they express uncertainty?”).

Regulative processing focused on task. All three groups focused their regulative processing primarily on the various aspects of the task and engaged little in the regulation of learning of the relevant subject matter content. As I mentioned previously, regulative focus on
task does not imply that learning was not happening, just that the groups’ regulation was primarily directed at various aspects of the task rather than the content. I was able to zero in on this finding using a granular coding scheme that included regulative codes for aspects of task and content (e.g., monitoring of task understanding and monitoring of content understanding), as well as the data from students’ blog posts that complemented the quantitative findings. Thus far, researchers on social regulation of learning have not systematically investigated this difference in regulative processing focused on aspects of task versus content (e.g., Iiskala et al., 2015; Ucan, 2017; Ucan & Webb, 2015). Hence, my study extends the existing research and points to an additional distinction that educators and researchers might find worth investigating further. My finding about groups’ focus on task regulation indicates that collaborative groups might need explicit support to be able to just as effectively and confidently regulate various aspects of subject matter content as they do for different aspects of task. For example, in Excerpt 5, from Task 2, after Kerry expressed uncertainty about the drop height (i.e., Turn 24) and validity of the trial (i.e., Turn 28), the group missed an opportunity to engage in monitoring and controlling of content understanding. Instead, they focused on moving forward with the task and calculating the average time for their drop trials. With timely and adequate prompting (i.e., external regulation), it is possible that the group would have been able to work through the identified content related issues. Moreover, akin to Iiskala et al. (2015), I speculate that such support might be even more relevant in open-ended tasks similar to tasks used in my study, where it is perhaps easier for the groups to focus on grappling with the task, rather than or in addition to what could be learned from it and how.

**Use of social comparison for regulation of learning.** In their regulation of learning, all three groups used social comparison with the other groups in the class to monitor and control
their own task plans and task progress, as well as to judge their work products. During the coding of the transcripts, both coders independently recognized the need to capture this phenomenon. Thus, codes for monitoring, controlling, and evaluating through social comparison were added to the codebook and used to mark such instances in the groups’ regulation of learning. My focus on the use of social comparison in regulative processing is different from its use in previous SSRL research. For example, researchers (e.g., Rogat & Adams-Wiggins, 2015) have used the construct of social comparison to describe negative socio-emotional interactions. I chose to not assign a valance to the emergent processing codes because I wanted to use these codes to capture the breadth of this phenomenon rather than to narrow down their exact valance for groups’ interactions.

In my study, in some instances, use of social comparison for monitoring led the group to engage in closer examination and preservation of their own plans (e.g., the UO group, Excerpt 7), whereas in others, the group altered their plans without too much debate (e.g., the Mixed group, Except 8). Yet, in other instances, especially in the CO group (e.g., Excerpt 37), monitoring through social comparison quickly escalated into competitive statements and fueled a focus on winning. This last finding is not surprising because social comparison is one of the sources of competitive behavior (Garcia et al., 2013), so I will return to it in the discussion of Research Question 2.

The main takeaway regarding my findings about regulation through social comparison is that it is not necessarily good or bad. Rather, the group conditions and the ways in which a particular group interacted with the task (i.e., Task X Group level) determined whether or not the social comparison was productive for group’s regulation of learning. I posit that these complex and dynamic processes surrounding social comparison warrant further research and examination.
I recommend that future researchers interested in use of social comparison in social regulation of learning might want to explore whether assigning a positive or negative valance to these codes would make sense and, if so, under what conditions. Such valanced coding would be conducive to the studies aimed at discerning and contextualizing adaptive and maladaptive use of social comparison in social regulation of learning.

The three qualitative themes discussed in this section highlighted similarities observed across the groups as they engaged in the series of collaborative tasks. Thus, despite differences in the groups’ uncertainty orientations, there were some nuanced commonalities in how the groups regulated their learning when they had to deal with uncertainty. In the next section, I focus on the observed differences in groups’ social regulation of learning across the series of five tasks of varying uncertainty levels.

**Discussion of Findings for Research Question 2**

Through my examination of differences in the groups’ enactment of social regulation during collaborative learning with respect to the groups’ uncertainty orientation and the degree of situational uncertainty in the task, I found three qualitative themes for each of the three groups. Over the course of the five collaborative sessions, the three distinguishing themes for each group worked synergistically to foster distinct group conditions that, in turn, resulted in unique social regulation of learning enacted by the groups in each task. I organize the rest of the discussion in this section by the broader concepts that encapsulate my findings.

**Task engagement and group dynamics.** The UO group spent, on average, more time on-task and less time off-task than the other two groups. In contrast, the CO group spent, on average, the least time on-task and the most time off-task. This finding aligns with uncertainty orientation theory that specifies the UO groups would be more engaged in situations which
require active exploration than the CO groups. As I previously pointed out, to engage on task or not is one of the first regulative choices a collaborative group makes. Additionally, Määttä et al. (2012) found a statistically significant relationship between groups’ science task involvement and the quality of their interaction, with the highest quality of interaction corresponding to the egalitarian and joint collaboration that aligns with SSRL mode of regulation. My findings suggest that groups of CO students may be less likely to engage in the kinds of SSRL that Määttä and colleagues found associated with science task involvement. The intersection of individual and group uncertainty orientations and a group’s regulative and collaborative engagement illuminated in my study might be of interest to the researchers on social regulation of learning, as well other educational researchers interested in facilitating high quality student engagement, so it is worth investigating further. I will return to this in the section on future directions.

In my study, the CO group’s off-task engagement increased with the task uncertainty level (i.e., as the task ill-structuredness increased), driven by their discomfort with uncertainty, but dropped to zero in Task 5, which was a linear design escape room where each puzzle had only one correct solution. I believe that the higher-level structure in Task 5 was instrumental for facilitating the CO group’s higher engagement. Although this task was a high-uncertainty task based on the level of uncertainty related to the solving of each puzzle, the linear design of the escape room provided a high level of structure. Based on this finding, Task 5 cannot be classified as an ill-structured task. So, I recommend that researchers focus on the type of uncertainty that stems from the task level of structure as a particularly salient task condition for future studies aimed at fleshing out the influence of the task conditions on engagement of CO groups. For example, a couple of ways to investigate this more deeply would be a study of social regulation of learning using a counterbalanced design of tasks with linear versus multilinear (i.e., multiple
possible solution paths) escape rooms, or of an escape room versus another open-ended task with a multitude of possible solutions.

The CO group was also characterized by a negative SE climate, which started with the baseline task and got worse through the semester, culminating in Task 4, with a group member (i.e., Kerry) engaging in an unprovoked act of disrespecting the group’s work, followed by the targeted ignoring of that member for several minutes by the rest of the group. This finding confirms findings from earlier studies, most notably from Linnenbrink-Garcia et al. (2011), that patterns of group interactions tend get established early on and persist over a series of tasks. Because the CO group had their lowest combined number of instances of low group cohesion and disrespect codes in Task 2, the low-uncertainty task, and then again in Task 5, I speculate that clear and firm structure of the escape room somewhat moderated the task uncertainty level and helped the CO group to stabilize and engage with less friction than they experienced in other tasks.

In the UO and Mixed groups, positive and sustained SE interactions led to a positive group climate, consistent with findings from previous studies (Bakhtiar et al., 2017; Linnenbrink-Garcia et al., 2011; Rogat & Linnenbrink-Garcia, 2011). Sustaining a positive SE climate took effortful regulative engagement: the UO and Mixed groups engaged in control of their emotions, especially in Tasks 3 through 5, the medium- and high-uncertainty tasks. Similar to my findings for the UO and Mixed groups, Ucan (2017) observed that as the tasks became more complex, groups engaged in regulation of their emotions and motivation more often to overcome experienced challenges. Surprisingly, the CO group in my study did not follow this pattern and did not engage in control of their emotions, despite experienced challenges. This finding is new and significant because it points to the need to consider the differential influence
of uncertainty orientations as a part of person and group conditions for not only the regulative processes that will take place but also for those that may not. Researchers investigating SE regulation of learning might use my finding as a departure point for investigating groups’ maladaptive SE regulative responses, including but not limited to the absence of regulation, as well as ways to support students in enactment of productive SE regulation. This work might be particularly important for groups of CO students. Next, I discuss qualitative themes related to the differences in strategies groups of different uncertainty orientations used to deal with varying levels of situational uncertainty across the five collaborative tasks.

**Differentiating strategies for dealing with uncertainty.** Each group had a unique way of dealing with the encountered uncertainty: the UO group actively approached it; the CO group avoided active resolution of it, and the Mixed group was generally untroubled by it. The findings about the UO group’s active approach to uncertainty and attempts to resolve it, as well as the CO group’s avoidance of uncertainty, align with uncertainty orientation theory (Brouwers & Sorrentino, 1993; Shuper et al., 2004; Sorrentino & Roney, 2000). To my knowledge, my “in-situ” study is the first study to contribute to the literature with qualitative descriptions of what active resolution and avoidance of uncertainty look like in a real-life classroom, as well as how they potentially relate to groups’ regulation of learning and SE climate. Moreover, my study expands on the literature and contributes new knowledge about behaviors and regulation of learning of the Mixed group, which included participants of moderate uncertainty orientation, who typically have been excluded from studies on uncertainty orientations (Sorrentino & Short, 1977).

For the UO group, their active pursuit of resolution of uncertainty and related decision-making played a role in this group spending on average more time on-task and less time off-task
than other groups. This group often continued to work during debriefing sessions or even after others were done, demonstrating unparalleled on-task persistence. In addition to their task engagement, the group’s active resolution of uncertainty was reflected in the modes and quality of their social regulation of learning. During their collaborative work, the UO group relied more on SSRL and coRL than on group members’ individual SRL and external regulation of learning. The UO group was characterized by the positive SE climate that they actively controlled. The UO group engaged in less planning than the other two groups. This finding might indicate the UO group’s recollection of potentially effective task strategies was more automated. Typically, more automated processing happens when learners possess prior knowledge and relevant previous experiences (Pintrich, 2000). Thus, it is possible that the UO group’s processing was more automated, therefore they had no need to engage in overt planning as much as the other two groups. It is also possible that because group members were uncertainty-oriented they were more comfortable moving ahead to the task execution phase (i.e., Phase 3; Winne & Hadwin, 1998) more quickly than the other two groups.

For the CO group, their avoidance of active engagement in the resolution of uncertainty also influenced both the enacted modes and the quality of social regulation of learning. This group had a higher percentage of SRL in all tasks than the other two groups. Taking into account that the CO individuals prefer situations of high certainty and avoid the discomfort caused by uncertainty (Huber et al., 1992; Shuper et al., 2004), it is not surprising that the group showed a tendency to ignore group members when they articulated uncertainty. These actions further contributed to the negative SE climate, which impacted the quality of the group’s social regulation of learning.
My findings about the Mixed group’s unique propensity to remain untroubled by uncertainty, sometimes articulating it but leaving it unresolved, and sometimes working together to address it, expands the existing literature on uncertainty orientation, adding new knowledge about the behavior of a Mixed group, which contained participants of moderate uncertainty orientations, in real classroom conditions. The finding about the Mixed group’s inclination to articulate uncertainty and then leave it open might be particularly interesting for the socially-shared metacognitive regulation (SSMR) researchers. SSMR researchers focus on studying aspects of metacognition related to identification of task requirements, planning, monitoring, controlling, and evaluating the task outcomes. Research on regulation of learning has suggested that when collaborative groups detect a dissonance through monitoring, they follow up with adaptations to address it (i.e., they engage in controlling; Iiskala et al., 2015; Ucan & Webb, 2015). The Mixed group in my study often did not follow this regulative path. Because uncertainty orientation theorists offered no explanation for this finding (Shuper et al., 2004; Sorrentino & Short, 1977), I had to look for an alternative explanation for this phenomenon.

I hypothesize that the need for cognitive closure (Webster & Kruglanski, 1994) might be another salient psychological construct that researchers ought to consider as they attempt to explain groups’ lack of action after detecting and articulating uncertainty. As a reminder, need for cognitive closure is a motivational variable (Kruglanski & Webster, 1996), whereas uncertainty orientation is an information processing variable (Shuper & Sorrentino, 2004). Researchers found individuals who have a strong resistance to closure are motivated to maintain uncertainty and avoid definitive closure, thus they suspend judgment as they engage in systematic evaluation of available options, resulting in more complex and flexible decision-making (Kruglanski & Webster, 1996; Rydzewska et al., 2018; Webster & Kruglanski, 1994).
Thus, complex interaction between task conditions, uncertainty orientations, and need for cognitive closure might be responsible for the Mixed group’s unique propensity to sometimes resolve uncertainty and sometimes identify it but leave it unresolved. One way that researchers could further investigate this potential interaction in the future would be to administer both measures of uncertainty orientation and the need for cognitive closure to the study participants and then observe their behavior in tasks of different uncertainty levels.

**Help-seeking behaviors and use of learning strategies.** I found that the three groups differed in who and what they relied on for support when they encountered uncertainty that hindered their task progress: the UO group members relied on each other; the CO groups relied on appeals to the perceived authority (i.e., the instructor or the teaching assistant), and the Mixed group relied on skillful use of learning strategies. SRL researchers have accumulated a substantial amount of work on the topic of help-seeking and identified effective help-seeking as an important regulative strategy that facilitates learning and is another hallmark of proficient self-regulators (Pintrich, 2000). However, little is known about help-seeking in the context of social regulation of learning (Järvelä, 2011). Hence, my study contributes important new knowledge about how help-seeking behaviors emerge in collaborative groups and provide a base from which to build an understanding of complex factors that drive help-seeking in social settings.

The groups in my study engaged in both adaptive (i.e., mostly the UO and the Mixed group) and dependent help seeking (i.e., mostly the CO group). The UO group members relied on the group’s internal resources to support each other. They respectfully asked for and offered help to each other, thus maintaining and fostering good group cohesion. The UO group members sought help from each other to overcome challenges related to uncertainty and to advance their
understanding. The CO group relied on appeals to authority for resolution of uncertainty, using it as a heuristic that replaced analytic thinking, as predicted by uncertainty orientation theory. They engaged in external help-seeking three times as much as the other two groups. Their help-seeking was often driven by a desire to obtain a quick and correct answer to the challenge at hand from the instructor, thus their help-seeking was dependent and maladaptive.

The Mixed group mostly relied on flexible and adaptive use of learning strategies to navigate through the tasks and complete them. This finding suggests that the Mixed group possessed solid conditional metacognitive knowledge (i.e., they understood when and why to use specific strategies to meet their goals; Pintrich, 2000). The Mixed group also engaged in modification of regulation targets to produce the desired outcomes (e.g., implementing monitoring of environment in Task 5). As I demonstrated in the findings for Research Question 2, they used the top four learning strategies more than the other two groups and did so at the critical moments in the task and more skillfully than the other groups. Their approach made the greatest difference in Task 5 when they engaged in systematic monitoring and control of the environment and were ultimately the first group to complete the task.

With this study, I contributed to the literature knowledge about help-seeking behaviors in collaborative groups of different uncertainty behaviors. Patterns of help-seeking behaviors in the UO and Mixed groups were adaptive, whereas the CO group used external help-seeking maladaptively, as a heuristic to orient towards certainty and avoid active engagement in the resolution of uncertainty. In the next section, I consider how differences in the groups’ foci related to their regulation of learning.

**Collaborative groups’ distinguishing foci.** Qualitative analysis revealed that each of the three collaborative groups had a distinct focus as they navigated through uncertainty. The UO
group focused on achieving creative solutions; the CO group focused on winning, and the Mixed group’s regulation was guided by their focus on task parameters. Differences in the groups’ foci indicate existence of differences in the standards and goals they set for their performance as well as in their goal orientations (i.e., mastery versus performance). Whereas SRL researchers have extensively studied goals, researchers on social regulation of learning have not thus far illuminated how the development and subsequent execution of group goals can shape the group’s regulation of learning (Lyons, 2019). Hence, my study contributes new knowledge that builds on findings from SRL literature that individual goals arise from individual differences and contextual factors (Pintrich, 2000) and offers insight into how group goals were shaped by individual and group differences in uncertainty orientations and the context in which collaborative learning unfolded.

My finding about the UO group’s focus on creative solutions aligns with the suggestion of uncertainty orientation theorists that the UO individuals orient towards novel solutions because they offer an opportunity for the UOs to master the uncertainty and learn new things (Sorrentino & Roney, 2000). The UO group’s focus on creative solutions was intrinsically driven and reflective of the group’s mastery orientation. They pursued creative solutions, although the group needed to exert more effort and spend more time on implementing them than they would need to spend on a simpler solution. The group’s pattern of adaptive attributions (e.g., Excerpt 21) and positive group climate further supports the preposition that the group had mastery goal orientation (Pintrich, 2000). To execute their creative solutions, the UO group engaged in controlling more than the other two groups, accounting for almost half of all instances of controlling. The group perceived task parameters to be flexible and excluded them from their own standards when they interfered with the group’s general goal of pursuing creative solutions.
In contrast with the UO group’s mastery goal orientation, the CO group’s focus on winning reflects the group’s extrinsic orientation to the classroom conditions and group’s performance goal orientation. Uncertainty orientation researchers did not specifically address focus on winning or competitive drive in their theory (Shuper et al., 2004; Sorrentino & Roney, 2000). However, as I mentioned earlier, they posited that CO individuals use information from their groups as a source of self-verification and shared reality (Sorrentino & Roney, 2000). Hence, it is possible that the CO group’s shared focus on winning might have been a heuristic to achieve these goals and set the group apart from others. Additional relevant insight can be gleaned from the social comparison model of competition, which shows that individual factors encompassed by situational factors combine to influence the degree of comparison concerns, and thus, competitive behavior (Garcia et al., 2013). Hence, the CO group members’ uncertainty orientations combined with the task conditions to create a stronger competitive focus than in the other two groups, resulting in the CO group’s greater reliance on social comparison in their regulation of learning and competitive behavior.

The Mixed group’s focus on satisfying instructor-specified task parameters, although stable, is reflective of their goals that can be characterized as task-specific goals rather than an overarching goal orientation (Pintrich, 2000). Task-specific, proximal goal setting involves breaking larger tasks into smaller segments that are simpler, easier to accomplish (Wolters, 2003), and conducive to learning (Pintrich, 2000). By incorporating task parameters into their standards and goals, the group ensured that their work product met the task requirements. Hence, goals set by the Mixed group were adaptive for social regulation of learning and instrumental for achieving the task learning goals. The finding that this group also engaged in monitoring of content understanding more than the other two groups, provides additional support for
demonstrating how the group’s goals might have helped to shape productive social regulation of learning by facilitating a stronger focus on learning objectives involving content understanding.

I found that the groups’ foci were reflected in their regulative targets. For example, the UO group evaluation target was the success of their plan, which typically involved a non-standard solution. The CO group evaluated through social comparison and evaluations of group members’ behavior; these targets were a reflection of the group’s internal dynamics and competitive drive. The Mixed group’s engagement in evaluations without the comparison component was a reflection of their approach focused on fulfilling task parameters and their positive group dynamics. My findings respond to the recent calls from SSRL researchers and contribute to the SSRL literature (Hadwin et al., 2018; Panadero & Järvelä, 2015), providing a way to trace how individual differences influence and shape the formation of group standards and global goals, which then shape a group’s regulative processes and targets and form the group’s distinct social regulation of learning and unique work products (i.e., creative solutions vs. more standard approaches).

Limitations of the Study

Triangulation across measurement protocols. In this study, I chose to rely on observation of regulative performance because of the two strengths of this approach identified by Winne and Perry (2000), which were particularly important for my study: (a) it affords a look at what learners in groups do, rather than what they believe or claim they do, and (b) it allows for connecting of task conditions and learner behaviors. An additional strength of my study stems from my use of data triangulation. Namely, to ensure trustworthiness of my study, I triangulated my findings based on video-observations with findings based on the participants’ prospective pre-task responses and retrospective reflections (i.e., blog posts). However, one limitation of my
study was that I did not use triangulation across other measurement protocols typically used in studies of regulation of learning (e.g., questionnaires, interviews, etc.). In particular, this study could have benefited from triangulation with two additional measurement protocols commonly used in SRL studies: stimulated recall interviews and questionnaires.

Stimulated recall interviews, like observations of performance, are a measurement protocol used to measure and describe regulation of learning as an event (Winne & Perry, 2000), which is how I approached social regulation of learning in this study. Individual, stimulated-recall interviews with group members in which I could show group members videos of their group interactions and ask them about their individual as well as the group’s regulation of learning in response to uncertainty would contribute another perspective to the understanding of ways in which people in collaborative groups deal with uncertainty. Perhaps being in a one-on-one confidential setting with the researcher and free from the scrutiny of their group members and the course instructor would incline students to provide additional insight into how the regulation unfolded in particular episodes and over the series of tasks. Questionnaires are typically used in studies that investigate SRL as an aptitude, so including one such questionnaire would have added an additional dimension to the study. Hence, a study with three measurement protocols would have furthered understanding of the dual nature of regulation of learning as an event and as an aptitude.

**Measures of domain knowledge.** In this study, I included no measures of students’ domain knowledge. Consequently, it was not possible to discern when and how the students’ science expertise might have shaped their social regulation of learning or vice versa. Learners who are more proficient in a domain might automate some of the regulative processing in which less proficient learners might still need to engage (Greene, 2018). For example, it is possible that
the UO group was able to engage in less planning in Task 2 and quickly decide on pursuing a non-standard solution of increasing air resistance to slow down their parachute because they had greater science content knowledge. The CO and the Mixed groups’ greater engagement in planning in Task 2 and their decisions to settle on design modifications suggested during the whole-class discussions might have been driven by the groups’ lesser content knowledge. My decision to not include pre- and post-tests of domain knowledge was driven by my desire not to overwhelm participants with a battery of tests at the start of the study. Thus, my decision was a tradeoff aimed at balancing the need to perform data collection that can cause a disturbance with a desire to preserve the typical learning conditions in a science methods course.

Population characteristics. Another limitation of the study stems from the population from which I drew my sample of participants. Preservice teachers at this institution and in this course tend to be predominantly white females of middle socioeconomic status. Although I have attempted to include participants of other races and genders during the collaborative group formation (e.g., the Mixed group), low overall variation in the cohort limited my ability to create a more diverse participant pool. Therefore, a concern remains that my findings might be too specific to groups that are predominantly white, female, and in teacher training, and might not translate easily to more diverse groups or different settings.

Task nature. Several tasks used in this study had a strong engineering, design-based nature (i.e., egg drop experiment, straw tower design). Hence, in those tasks, participants experienced mostly design-related uncertainty. This engineering design task nature limited conclusions I could draw about participants’ responses to other kinds of scientific uncertainty, such as interpretive or conceptual uncertainty about science constructs or phenomena that might be experienced in more science-focused tasks. Hence, a study with all tasks focused on more
direct investigations of science phenomena would be better positioned to illuminate social regulation of learning arising in a response to these types of scientific uncertainty.

**Contributions and Suggestions for Future Research**

With this multimethod study, I am the first researcher to explore and describe how individual differences in uncertainty orientations of group members shape collaborative groups’ social regulation of learning through a series of science tasks of varying uncertainty levels. I explicated the participating groups’ ways of dealing with uncertainty and contributed new knowledge to the literature on social regulation of learning by providing one of the first insights into group standard and goal setting and the resulting social regulation of learning as well as into help-seeking regulative behaviors in collaborative group settings (Järvelä, 2011; Panadero & Järvelä, 2015; Volet & Mansfield, 2006). I found that the UO groups had an overarching goal of finding creative solutions, which could be characterized as a mastery orientation goal (Pintrich, 2000) and that they relied on the group’s internal resources for help. In contrast, the overarching goal of the CO group was winning, which reflected in the group’s performance goal orientation (Pintrich, 2000), and they relied on the authority figure (i.e., the instructor) to resolve encountered uncertainties. The Mixed group’s focus on task parameters indicates their goals were task-specific and conducive for productive engagement with content (Pintrich, 2000) as evidenced by the group’s higher engagement in monitoring of content understanding than was observed for the other two groups. By including participants of moderate uncertainty orientations in this study, the findings also contribute to the social psychology literature by providing new information about behaviors of groups that include mysterious moderates (Sorrentino & Short, 1977). By employing multiple methods of analysis and especially thick qualitative descriptions of the groups’ interactions, my study also adds to the methodological variety in the field of
research on social regulation of learning. This contribution is a necessary step toward building a contextualized understanding of social regulation of learning in science and identifying the domain-specific challenges and regulative triggers that small-groups experience.

My study highlights several potential directions for future research. In this study, I illuminated collaborative groups’ use of social comparison in regulation of learning. Because all three groups engaged in this behavior, this topic warrants more research to further describe and contextualize the phenomenon. I recommend that researchers explore whether assigning a positive or negative valance to social comparison regulative codes (i.e., codes such as monitoring through social comparison +) would be justified and productive. Such valanced coding might be conducive to the studies aimed at discerning and contextualizing adaptive and maladaptive use of social comparison in social regulation of learning.

My study also points the way for researchers interested in filling the existing gap in research on social regulation of learning related to the group goals and goal orientations as well as help-seeking behaviors. Thus far, researchers of social regulation of learning have not attended to these topics. Based on my findings that the groups’ goal orientations were reflected in their regulative processing as well their SE climate, I believe this would be a fruitful avenue for additional research. Observed differences in help-seeking behaviors also indicate that promoting proficient social regulation of learning will necessitate helping collaborative groups avoid maladaptive help-seeking that serves as a shortcut to the correct answer and does little to advance a group’s learning. In advancing the line of research on group goals and help-seeking behaviors, it would also be important to consider the role of students’ interest in science as it relates to goal formation and task engagement.
In recent studies, science education researchers have emphasized the productive nature of uncertainty in the science classroom (e.g., Manz, 2018). Although efforts to engage students in science practices infused by the uncertainties resembling those encountered by real scientists are commendable, findings from my study indicate that uncertainty is not necessarily productive for all students in all types of tasks, and might lead to disengagement and negative group dynamics. Hence, I advise a more cautious approach and additional research to discern the best ways to support students when the tasks do not match their typical way of dealing with uncertainty. For example, researchers could utilize sequencing studies to discern sequences of regulative processes that unfold in response to the specific types of challenges (i.e., cognitive, motivational, emotional) related to the encountered uncertainty. Such studies would help identify the types of support that are needed as well as particular moments in time when such support would be relevant. This research direction should include the consideration that students of different uncertainty orientations are likely to respond differently to the scaffolds embedded in the learning environment versus those provided by the teacher (e.g., UO students prefer embedded support, and CO students prefer teacher support).

Another interesting research direction would be investigating if and how students’ uncertainty orientations relate to the roles they take on in collaborative groups and, more specifically, to leadership roles within groups. In collaborative work, emerging leaders are characterized by taking an active role in groups’ learning processes through planning and organizing work, fostering group cohesion, and maintaining a positive group climate (Yamaguchi, 2001). Hence, it might be interesting to investigate which group members, as characterized by their uncertainty orientation, tend to emerge as leaders in tasks of different
uncertainty levels (e.g., what is the role of a single UO student in a CO group in a high-uncertainty task).

Last, this study also points to several ways in which students might need to be supported in science classrooms where they are likely to engage in high-uncertainty tasks. A teacher in an everyday situation is not likely to have information about students’ individual uncertainty orientations, hence it is important to help teachers expand their understanding of both uncertainty orientations and social regulation of learning to effectively support all groups that are less than proficient social regulators of learning. For example, groups with lower quality regulation skills need to be supported in identifying and articulating the group’s SE challenges in a respectful manner and then in adequately resolving them. My study indicates that students need to be supported in learning how to regulate various aspects of content in addition to regulating various aspects of a task. Researchers and educators might consider ways to provide students with opportunities to engage in social comparison that orients them towards mastery, rather than performance. Providing such opportunities might lead to constructive harnessing of a dynamic that left unchecked might take some groups in unproductive directions.

Conclusion

In this multimethod study, I explored social regulation of learning that occurs when collaborative groups of preservice elementary school teachers engage in a series of five science tasks and grapple with the encountered uncertainty. Because uncertainty is an integral part of science, I designed a study in which I took into account individual differences in group members’ uncertainty orientations. I observed social regulation of learning in three purposefully selected groups with a majority of participants who were UO, CO, and of moderate uncertainty orientations. Because groups differed in their uncertainty orientations, I expected that their social
regulation of learning in the face of uncertainty might differ. For my analysis, I relied on sociocultural discourse analysis of video-observations of the groups’ collaborative sessions.

I found that there were similarities as well as fundamental differences in the groups’ social regulation of learning. Common themes for the three groups were: (a) a collaborative approach to resolving uncertainty, (b) regulative processing focused on the task, and (c) use of social comparison for regulation of learning. The UO, CO, and the Mixed group differed in: (a) how they dealt with uncertainty (i.e., active pursuit of uncertainty, avoidance of uncertainty, or being untroubled by it), (b) who and what they relied on to navigate through it (i.e., support within the group, appeals to the external authority, or skillful use of learning strategies), and (c) what they focused on (i.e., creative solutions, winning, or staying within task parameters). This study provides the first look into how individual differences in uncertainty orientations shape groups’ social regulation of learning in a series of science tasks of varying uncertainty levels. I suggest future research include additional complementary measurement protocols and measures of student content knowledge while aiming to expand to different populations and contexts for science learning.
**APPENDIX A: THE THREE DIMENSIONS OF THE NGSS**

<table>
<thead>
<tr>
<th>Scientific and engineering practices</th>
<th>Crosscutting concepts</th>
<th>Disciplinary core ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Asking questions (for science) and defining problems (for engineering)</td>
<td>Patterns</td>
<td>PS1: Matter and its interactions</td>
</tr>
<tr>
<td>2. Developing and using models</td>
<td>Cause and effect: Mechanism and explanation</td>
<td>PS2: Motion and stability: Forces and interactions</td>
</tr>
<tr>
<td>3. Planning and carrying out investigations</td>
<td>Scale, proportion, and quantity</td>
<td>PS3: Energy</td>
</tr>
<tr>
<td>4. Analyzing and interpreting data</td>
<td>Systems and system models</td>
<td>PS4: Waves and their applications in technologies for information transfer</td>
</tr>
<tr>
<td>6. Constructing explanations (for science) and designing solutions (for engineering)</td>
<td>Structure and function</td>
<td>LS2: Ecosystems: Interactions, energy, and dynamics</td>
</tr>
<tr>
<td>7. Engaging in argument from evidence</td>
<td>Stability and change</td>
<td>LS3: Heredity: Inheritance and variation of traits</td>
</tr>
<tr>
<td>8. Obtaining, evaluating, and communicating information</td>
<td></td>
<td>LS4: Biological evolution: Unity and diversity</td>
</tr>
<tr>
<td>9.</td>
<td></td>
<td>ESS1: Earth’s place in the universe</td>
</tr>
<tr>
<td>10.</td>
<td></td>
<td>ESS2: Earth’s systems</td>
</tr>
<tr>
<td>11.</td>
<td></td>
<td>ESS3: Earth and human activity</td>
</tr>
<tr>
<td>12.</td>
<td></td>
<td>ETS1: Engineering design</td>
</tr>
<tr>
<td>13.</td>
<td></td>
<td>ETS2: Links among engineering, technology, science, and society</td>
</tr>
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</table>

**Note:** PS = Physical sciences; LS = Life sciences; ESS = Earth and space sciences; ETS = Engineering, Technology, and Applications of Science. Adapted from “Next Generation Science Standards: For States, by States” by NGSS Lead States, 2013.
## APPENDIX B: DISSCOURSE MARKERS OF UNCERTAINTY

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<th>CO Group</th>
<th>Mixed Group</th>
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<td>0</td>
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<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>413</strong></td>
<td><strong>298</strong></td>
<td><strong>323</strong></td>
<td><strong>1034</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Note.* UO = Uncertainty-oriented. CO = Certainty-oriented.
## APPENDIX C: SOCIAL REGULATION OF LEARNING CODEBOOK

### Social Regulation of Learning Primary Codes: Modes of Regulation of Learning.

<table>
<thead>
<tr>
<th>Type</th>
<th>Code</th>
<th>Description with empirical indicators</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode of social regulation of learning</td>
<td>SRL</td>
<td>A group member regulates her or his own cognition, behavior, motivation or emotions: a group member identifies something she or he does not understand, needs to do, or has done related to the learning task. Emphasis is on the word <em>I</em>.</td>
<td>Kerry: “I don’t know how to make it slower.”</td>
</tr>
<tr>
<td></td>
<td>CoRL</td>
<td>One or multiple group members temporarily guide regulation of one or multiple other members in the group: a group member prompts others to engage in the task or explains how they think the group should proceed on the task. Other members acknowledge the effort or the idea but do not contribute anything new to the discourse. Emphasis is on the word <em>you</em>.</td>
<td>Emma: “It's just confusing, because they don't have ... They say we need push pin, ruler, and tape, and all that, and I don't get why.” Rose: “Well, ruler's to measure.” Julie: “Mm-hmm” (affirmative) Emma: “Oh, okay.” Rose: “Push pin and tape might be to hold this mumbo together.” Emma: “Okay.”</td>
</tr>
<tr>
<td></td>
<td>SSRL</td>
<td>Group members collectively regulate the group’s learning: Ideas and contributions of a group member are followed by uptake and contributions from at least one other group member. Emphasis is on the word <em>we</em> or collective <em>you</em>.</td>
<td>Emma: “How many cotton balls could we get if we put all the rest of the budget in the cotton balls?” Rose: “16. I think we should see how much bubble wrap we are getting for our [money]” Emma: “I think we need to see what this stuff looks like” Sarah: “Yeah, I agree. I think we need to make an informed purchase with the rest of our money.”</td>
</tr>
<tr>
<td>Other modes of regulation</td>
<td>External regulation</td>
<td>Someone outside the group (i.e., teacher) temporarily guides regulation of one or multiple members of the group: someone outside of the group monitors the progress and understanding, prompts group members to engage in the task, or explains how they think the group should proceed on the task. Group members acknowledge the effort or the idea but do not contribute anything new to the discourse. Emphasis is on the word <em>you</em></td>
<td>Emma: (To the instructor:) Is there ... should we tape this on? Instructor: “Yes, you're going to tape that. Did you tape the middle part? Emma: “Nope.” Instructor: “Might need to do that.” Emma: Okay. (She leaves the table, looking for tape.)</td>
</tr>
</tbody>
</table>

**Note:** All examples are from the present study.
### Social Regulation of Learning Secondary and Tertiary Codes: Regulative Processes with Targets.

<table>
<thead>
<tr>
<th>Secondary code</th>
<th>Tertiary code (code abbreviation)</th>
<th>Description with empirical indicators</th>
<th>Example</th>
</tr>
</thead>
</table>
| Planning       | Task planning (TP)               | Students read and interpret task directions, designate group roles, plan resources, discuss potential solutions and how to implement them. Includes discussing the overall goal or sub-goals for the task at hand. | Julie: “Maybe joint this together?”
|                |                                  |                                        | Rose: “Oh, we could, yeah, just the little bit of tape.” |
| Planning       | Planning content (PC)            | Students read and interpret relevant science content and relate it to the task at hand. Learners discuss how the content relates to the completion of the task or subject matter content to be included in their task work products. | Kate: “… So for reasoning, do we just want to say like obviously the lettuce and the cabbage or greens or food?” |
| Monitoring     | Monitoring content understanding (MCU) | Students track sufficiency of their content understanding. | Jane: “At first, I was thinking weight, but that's a misconception.” |
| Monitoring     | Monitoring task understanding (MTU) | Students track sufficiency of their understanding of the task (i.e., requirements, constraints, procedures). | Kate: “Are we just timing the time it takes to fall?”
<p>|                |                                  |                                        | Stella: “Yeah” |
| Monitoring     | Monitoring task plan understanding (MTPU) | Students track various aspects of their task plan and its effectiveness. | Stella: “Are we going to have a way to put a clip at the bottom then, I guess?” |
| Monitoring     | Monitoring progress (MP)         | Students track adequacy of their advancement through the task. | Emma: (As she attempts to puncture a hole in the cup) &quot;Oh, we're getting there.” |
| Monitoring     | Monitoring emotions (ME)        | Student realizes that he/she is having an emotional response due to some aspect of the task. | Jane: “I hate that we can't start building this.” |
| Monitoring     | Monitoring motivation (MM)      | Students gauge their motivation to engage in and persist in task-oriented activities. | Laura: “Honestly, it's a cage for me if it doesn't work, because I'm just like over it.” |</p>
<table>
<thead>
<tr>
<th>Secondary code</th>
<th>Tertiary code (code abbreviation)</th>
<th>Description with empirical indicators</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring behavior (MB)</td>
<td></td>
<td>Students gauge adequacy and impact of their behavior on task.</td>
<td>Rose: (Laughs) “You broke the foundation.”</td>
</tr>
<tr>
<td>Monitoring environment (MEnv)</td>
<td></td>
<td>Students realize that some aspect of the environment is less than optimal.</td>
<td>Jane: “There's too many papers.”</td>
</tr>
<tr>
<td>Monitoring other aspects of the task (MT)</td>
<td></td>
<td>Students track some additional aspect of the task that is of interest to them (i.e., pedagogical application of the task, usability of the technology).</td>
<td>Julie: “I really can’t imagine doing this with a class.”</td>
</tr>
<tr>
<td>Monitoring through social comparison (MSC)</td>
<td></td>
<td>Students gauge various adequacy of their task progress or solution against other groups or individuals in the classroom.</td>
<td>Alice: “I think everybody else has started, y'all.”</td>
</tr>
<tr>
<td>Monitoring work of others</td>
<td></td>
<td>Students track other groups’ task progress or solutions without comparing it to themselves.</td>
<td>Sarah: “Oh, look at that structure.” Julie: “Structurally sound!”</td>
</tr>
<tr>
<td>Monitoring exhaustion</td>
<td></td>
<td>Students gauge their levels of energy needed for task participation.</td>
<td>Sarah: “I'm feeling a little depleted.”</td>
</tr>
<tr>
<td>Controlling</td>
<td>Controlling content understanding (CCU)</td>
<td>Students implement change to improve their content understanding.</td>
<td>Sarah: “I'm like fairly confident it's 30, but I'll just look at it.” (Sarah walks around the table and looks through the papers.)</td>
</tr>
<tr>
<td>Controlling task understanding (CTU)</td>
<td></td>
<td>Students clarify aspects of the task that were not well understood (i.e., requirements, constraints, procedures, etc.) either through discussion or by consulting reference materials or other people.</td>
<td>Sarah: “I'm wondering though, no one ever said it [the straw tower] had to be elevated.” Rose: “I feel like it's kind of implied.” Julie: “Yeah.”</td>
</tr>
<tr>
<td>Controlling task plan (CTP)</td>
<td></td>
<td>Students adapt some aspect of their task plan to improve its effectiveness.</td>
<td>Julie: “I'm going to bring our tape over here.”</td>
</tr>
<tr>
<td>Controlling task progress (CP)</td>
<td></td>
<td>Students intervene to improve or foil advancement through the task.</td>
<td>Emma: “Wait, I want to watch.” Sarah: “Unleash the hang glide.”</td>
</tr>
<tr>
<td>Secondary code</td>
<td>Tertiary code (code abbreviation)</td>
<td>Description with empirical indicators</td>
<td>Example</td>
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<tr>
<td>Controlling emotions (CE)</td>
<td>Students actively work to remedy sub-optimal emotional responses (e.g., use of humor to alleviate frustration).</td>
<td>Julie: “How many combinations are there? Only a million?” Sarah: “Yeah, only a million.” (Julie, Sarah, and Emma laugh. Rose looks disappointed.) Julie: “Let's try them all.”</td>
<td></td>
</tr>
<tr>
<td>Controlling motivation (CM)</td>
<td>Students engage in conversation or activities to improve their motivation for engagement and persistence in task-oriented activities.</td>
<td>Sarah: “We could do anything.” Julie: “I am smart, I am clever, I can do anything.”</td>
<td></td>
</tr>
<tr>
<td>Controlling behavior (CB)</td>
<td>Students facilitate or enact a change in behavior to improve its adequacy and/or impact on task.</td>
<td>Laura: “Okay? Now, pack your things in.”</td>
<td></td>
</tr>
<tr>
<td>Controlling environment (CEnv)</td>
<td>Students change aspect of the environment that was less than optimal.</td>
<td>Tom: “All right, let's get rid of this [papers]. I feel like this is done now.”</td>
<td></td>
</tr>
<tr>
<td>Controlling through social comparison (CSC)</td>
<td>Students change their actions or task direction based on comparison to other groups or individuals in the classroom.</td>
<td>Jane: “Nice. Wait should we blow it up with air? “ Stella: “Yeah, definitely.” (P6 unzips the bag and starts adjusting the paper towels and egg inside.) Jane: “Like they did. Do like a small little…”</td>
<td></td>
</tr>
<tr>
<td>Controlling work of others</td>
<td>Students attempt to control behavior of other groups or individuals in them.</td>
<td>Kerry: (To the other group) “No, you gotta stand on the table.”</td>
<td></td>
</tr>
<tr>
<td>Evaluating</td>
<td>Evaluating task progress (ETP)</td>
<td>At end of session (or end of episode if changing directions), students evaluate factors that contributed to their progress.</td>
<td>Alice: “That was a great idea. That was a fantastic idea.”</td>
</tr>
<tr>
<td>Evaluating task completion (ETC)</td>
<td>At end of session (or end of episode if changing directions), students evaluate the completion of the task (i.e., determine if they finished the work).</td>
<td>Sarah: “Wooo. Pump it up, pump it up! We done.” Julie: “Boom. Nailed it.”</td>
<td></td>
</tr>
<tr>
<td>Evaluating content understanding (ECU)</td>
<td>At end of session (or end of episode if changing directions), students evaluate their content understanding.</td>
<td>“Our problem was that we did not realize that there was moisture in the ingredients, so we ended up adding too much tap water”*</td>
<td></td>
</tr>
<tr>
<td>Secondary code</td>
<td>Tertiary code (code abbreviation)</td>
<td>Description with empirical indicators</td>
<td>Example</td>
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<tr>
<td>Evaluating success of plan (ESP)</td>
<td>At end of session (or end of episode if changing directions), students evaluate success of their task plan.</td>
<td>Sarah: “The fact that we split up our paper towels, might have been our mistake.”</td>
<td></td>
</tr>
<tr>
<td>Evaluating behavior (EB)</td>
<td>At end of session (or end of episode if changing directions), students evaluate their behavior during the task and its impact on the task outcomes.</td>
<td>Alice: “I'm the doubter. Every group needs a doubter to push you to be better.”</td>
<td></td>
</tr>
<tr>
<td>Evaluating environment (EEnv)</td>
<td>At end of session (or end of episode if changing directions), students retrospectively evaluate conditions of the environment.</td>
<td>“The classroom was too noisy today.”*</td>
<td></td>
</tr>
<tr>
<td>Evaluating through social comparison (ESC)</td>
<td>At end of session (or end of episode if changing directions), students evaluate outcome of their task engagement to that of the other groups (i.e., comparing quality of groups’ work products, speed of work, creativity)</td>
<td>Kerry: “Ours is the discount version of theirs.”</td>
<td></td>
</tr>
<tr>
<td>Evaluating work of others</td>
<td>At end of session (or end of episode if changing directions), students evaluate outcome of other groups’ task engagement without comparing it to themselves.</td>
<td>Tom: (Impressed by another group’s design which is simple and effective) <em>Dang.</em> Stella: <em>That’s brilliant.</em> (Both Tom and Stella nod.)</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** * Denotes a hypothetical example. Inductive codes are marked in bold font. If an example contains multiple turns, relevant turns are marked in italic font. All names are pseudonyms.
<table>
<thead>
<tr>
<th>Secondary Code</th>
<th>Tertiary Code (code abbreviation)</th>
<th>Description with empirical indicators</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Learning Strategy (LS)</td>
<td>Reading or re-reading instructions (READ)</td>
<td>Reading from the task materials (blackboard, written instructions, web site, etc.)</td>
<td>Rose (Reads from the instructions): “Find a solution for growing food or fixing the soil.”</td>
</tr>
<tr>
<td></td>
<td>Restating task goal (RTG)</td>
<td>Stating previously identified task goal.</td>
<td>Stella: “So, we're just calculating the carbon-to-nitrogen ratio for each batch of the compost”</td>
</tr>
<tr>
<td>Help seeking (HS)</td>
<td>Asking for assistance to overcome the encountered challenge</td>
<td>Laura: “Instructor, could you explain this to me? It says 50 to one milliliters, so it's 50... This is one milliliter?”</td>
<td></td>
</tr>
<tr>
<td>External (HSE)</td>
<td>Asking a person external to the group for assistance</td>
<td>Rose: “What is the answer for this one? Isn’t it...Help me out, greens or browns?”</td>
<td></td>
</tr>
<tr>
<td>Internal (HSI)</td>
<td>Asking group members for assistance</td>
<td>Emma: “Uhm, greens.”</td>
<td></td>
</tr>
<tr>
<td>Taking notes (TN)</td>
<td>Writing down task related information.</td>
<td>Tom: “41 point five.” (Tom and Kate write it down on their sheets.)</td>
<td></td>
</tr>
<tr>
<td>Drawing (DRAW)</td>
<td>Creating task related drawings</td>
<td>Jane: “We need like a parachute type.” (Tom starts drawing on his sheet.)</td>
<td></td>
</tr>
<tr>
<td>Preliminary testing (PT)</td>
<td>Conducting a proof-of-concept test or testing the interim or final solution prior to presenting it to the whole class.</td>
<td>Jane: “Can we drop it upside down?” (Kate flips the parachute so that the strings are on top and lets it fall onto the table.)</td>
<td></td>
</tr>
<tr>
<td>Hypothesizing (HYP)</td>
<td>Making an informed guess or a tentative conclusion about some aspect of the task, based upon information either encountered in the environment (i.e., read, seen, heard) or from prior knowledge.</td>
<td>Rose: “Don't you think if it's insulated though, when it drops, it might cause it them tip over.”</td>
<td></td>
</tr>
<tr>
<td>“Just try it” strategy (JTI)</td>
<td>Attempting to progress through the task and resolve uncertainty by simply trying different solutions without providing supporting reasoning for why it may or may not work.</td>
<td>Stella: “Yeah. Maybe we just guess the number.”</td>
<td></td>
</tr>
<tr>
<td>Secondary Code</td>
<td>Tertiary Code (code abbreviation)</td>
<td>Description with empirical indicators</td>
<td>Example</td>
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</tbody>
</table>
| Check for errors | CHECK | Reviewing the task steps and procedures to locate mistakes | *(P6 and P2 start going through all the blanks again.)*  
Tom: “Yellow and red.” |
| Finger counting | COUNT | Using fingers to count and display task relevant quantities. |  
Parker: “Tea bag. That’s two.”  
*(Holds up two fingers.)*  
Kerry: “... And the tea bag. So two.”  
*(Holds up two fingers.)* |
| Memorization | MEM | Attempting to memorize task-relevant data to recall and use when needed later in the task |  
Sarah: “Just remember 34, okay?”  
Julie: “I got that. That can be my job.” |

*Note: Inductive codes are marked in bold font. All examples are from the present study. All names are pseudonyms.*
### Socio-emotional Interactions Primary and Secondary Codes

<table>
<thead>
<tr>
<th>Primary Code</th>
<th>Secondary Code (code abbreviation)</th>
<th>Description with empirical indicators</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive socio-emotional interactions (SE+)</td>
<td>Respect and active listening (R/AL)</td>
<td>At least one group member does any of the following: Conveying attention to other group members by making eye contact, leaning in, responding to a contribution, and sharing ideas, referencing someone else, etc.</td>
<td>Stella: (To Tom after he attached straws very quickly) “See, you've got the technique down.” (Both laugh.)</td>
</tr>
<tr>
<td></td>
<td>Inclusion (INC)</td>
<td>Encouraging participation of group members by explicitly asking for their ideas or through positive feedback to members who have not been very active.</td>
<td>Julie: “I'm really interested in your idea, Emma.”</td>
</tr>
<tr>
<td>Fostering group cohesion (FGC)</td>
<td></td>
<td>Communicating that the group functions as a team (rather than as individuals); referring to the group as “we”</td>
<td>Stella: “We're so good at this.” (All students smile.)</td>
</tr>
<tr>
<td>Mistakes as learning opportunities (MLO)</td>
<td></td>
<td>Mistakes are addressed in supportive and constructive manner and perceived as occasions to improve task approach or task or content understanding</td>
<td>Tom: “Sorry. Ahh, I messed up something. Restart, sorry.”</td>
</tr>
<tr>
<td>Discouraging marginalization (DM)</td>
<td></td>
<td>Intervening in instances of exclusion.</td>
<td>“Just let her explain her idea!”*</td>
</tr>
<tr>
<td>Negative socio-emotional interactions (SE-)</td>
<td>Disrespect (DIS)</td>
<td>Actions group members would consider disrespectful, such as putting-down or ignoring a member of the group, smirking, grabbing papers away without permission, etc.</td>
<td>Alice: (Looking at her sheet) Okay, plastic bag is a required purchase. We already have 50. So, I'm going to do 500 minus 50. (Alice and Laura write on their sheets.) <em>(Kerry chuckles.)</em></td>
</tr>
<tr>
<td></td>
<td>Targeted ignoring/rejection (TIR)</td>
<td>Undermining a group member’s task contributions by ignoring their statements or questions or obstructing their task participation in some way.</td>
<td>Kerry: “It's very difficult to show and hold it at the same time. All right. What if we did like a base in the middle? Like this.” <em>(She holds together)</em></td>
</tr>
<tr>
<td>Primary Code</td>
<td>Secondary code (code abbreviation)</td>
<td>Description with empirical indicators</td>
<td>Example</td>
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</tr>
<tr>
<td>Low group cohesion (LGC)</td>
<td>Communicating that the group does not function as a team by not acting as a unit or team or by prioritizing individual benefit over group.</td>
<td>(Everyone ignores her.)</td>
<td></td>
</tr>
<tr>
<td>Mistakes as negative (MAN)</td>
<td>Treatment of errors as indicators of incompetence and stigmatizing and/or punishing those who made mistakes.</td>
<td>“You messed that up. That was just dull.”*</td>
<td></td>
</tr>
<tr>
<td>Discouraging participation (DP)</td>
<td>More active than targeted ignoring or low group cohesion; sustained and open criticisms of other’s work, ignoring or rejection of contributions, help offers, or help requests by a group member.</td>
<td>“You know you are not good with summarizing. Just let him do it.”*</td>
<td></td>
</tr>
<tr>
<td>Social comparison (SC)</td>
<td>Statements that create a competitive environment through negative evaluation of others.</td>
<td>“Well, I’m the only one who took AP Biology, so I know this better than y’all”*</td>
<td></td>
</tr>
</tbody>
</table>

* Denotes a hypothetical example. Inductive codes are marked in bold font. All names are pseudonyms.
Figure D.1. Monitoring targets by group by task. MTP = Monitoring task plan. MTU = Monitoring task understanding. MP = Monitoring progress. MCU = Monitoring content understanding.
Figure D.2. Controlling targets by group by task. CTP = Controlling task plan. CTU =
Controlling task understanding. C Env = Controlling environment. CE = Controlling emotions.
CB = Controlling behavior.
Figure D.3. Evaluating targets by group by task. Note. ESP = Evaluate success of plan. ETP = Evaluate task progress. ETC = Evaluate task completion. ESC = Evaluate through social comparison.
REFERENCES


Grau, V., & Whitebread, D. (2012). Self and social regulation of learning during collaborative activities in the classroom: The interplay of individual and group cognition. *Learning and Instruction, 22*(6), 401-412. doi:http://doi.org/10.1016/j.learninstruc.2012.03.003


Mercer, N. (2010). The analysis of classroom talk: Methods and methodologies. *British Journal of Educational Psychology, 80*(1), 1-14. doi:10.1348/000709909X479853


