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Investigating Maine Secondary Science Teachers Conceptualization of Scientific Argumentation

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INVESTIGATING MAINE SECONDARY SCIENCE TEACHERS CONCEPTUALIZATION OF SCIENFTIFIC ARGUMENTATION

By

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A THESIS

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Thesis Advisor: Asli Sezen-Barrie

An Abstract of the Thesis Presented
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The Next Generation Science Standards (NGSS) aims to reform science education for grades K-12 with a central focus on students becoming *doers of science* as opposed to just being *knowers of facts.* This historical shift in standards across the United States asks for teaching science content paired with eight Science and Engineering Practices. One of the eight Science and Engineering Practices is *Engaging in Argument from Evidence,* which is using empirical evidence and scientific reasoning to make sense of scientific phenomena. This study examined how the practice of Engaging in Argument from Evidence is conceptualized by Maine secondary science teachers, and how these teachers approached uncertainty when students are engaging in argumentation practice. The state of Maine officially adopted the NGSS in April 2019, making the 2019-2020 academic school year the first time the standards would be integrated into the public school's secondary science classrooms. Therefore, this is a critical time to understand how secondary school teachers in Maine make sense of the scientific practices and make suggestions for future professional learning of teachers.

In this study, a statewide survey was distributed to Maine secondary science teachers that asked them a series of questions about their conceptualization and implementations of the practice Engaging in Argument from Evidence. Out of the 37 survey respondents, interviews

were then conducted with 7 selected participants, who were asked to elaborate on their survey answers and provide examples of using argumentation practice in their classroom.

Results showed teachers paid attention to some aspects of the practice Engaging in Argumentation from Evidence from the participants more than others. The aspects that are frequently highlighted by these teachers included *Making Sense of Data* and *Communicating Arguments* when their students where actively engaging in the practice. Other characterizations included *Use of Multiple Scientific Practices, Integrating Scientific Reasoning, Use of Prior Knowledge* and *Use of Reliable Resources.* In the survey, teachers were asked if they integrated topics they considered to be uncertain, and if they did, if they allowed for competing claims when students were arguing these topics. When interview participants were asked about their integration of uncertainty when practicing scientific argumentation, there were three different interpretations of how their type of topics were integrated. These variations of uncertainty included *Measurement Uncertainty, Students Lack of Prior Knowledge* and *Controversial Issues (uncertain topics).*

Using the results, suggestions could be made on how teachers can integrate this practice in their classrooms to cohesively use. Future research can build upon how teachers implement uncertainty in their classroom by promoting opportunities for teachers to learn and actively engage with the such topics through the practice of Engaging in Argument from Evidence.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The most recent science standards in the U.S. Next Generation Science Standards (NGSS) intend to reform science education by suggesting learning environments that allow students to engage in meaningful scientific practices (NGSS, 2013). The last time a science curriculum got introduced into national standards was in 1996 with the National Science Education Standards (NSES, 1996). With all the advancements in science, technology, and educational research, it is time that new standards shift the science classroom for students to become more engaged in their learning of scientific ideas. The Framework (NRC, 2012), published in preparation for NGSS states the following:

> The framework is designed to help realize a vision for education in science and engineering in which students, over multiple years of school, actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of core ideas in these fields. (National Research Council [NRC], 2012, p. 10)

When implementing NGSS, there is a focus on scientific and engineering practices as well as the core ideas and crosscutting concepts for each of these scientific disciplines: physical science, life science, earth science, and engineering. NGSS document (2013) highlights eight scientific and engineering standards: 1) Asking questions and defining problems, 2) Developing and using models, 3) Planning and carrying out investigations, 4) Analyzing and interpreting data, 5) Using mathematics and computational thinking, 6) Constructing explanations and designing solutions, 7) Engaging in argument from evidence and 8) Obtaining, evaluating and communicating information.

This current study is focusing on the practice of *Engaging in Argumentation from Evidence*, in this study will be also be referred to as Scientific Argumentation. Through scientific argumentation, scientists refute and counter scientific claims to discover phenomena. Scientists rarely work in isolation and are usually surrounded by colleagues that provide feedback, suggestions, and insight to ensure that discoveries do not include flawed evidence. Engaging in argumentation makes the science content purposeful through the processes sensemaking, articulating, and persuading (Berland & Reiser, 2008).

The role of argumentation is critical in understanding the nature of science. For this reason, science education scholars have called for an urgent need to improve young people's learning to engage in argumentation from evidence (Osborne et al., 2004). Through argumentation practices, students have more opportunities to interact with the educational materials and with their peers directly. Previous studies showed that when students take part in argumentation practices, they may become more aware of their flaws in their understanding of scientific theories; trying to untangle these flaws could trigger argumentation (Asterhan & Schwarz, 2007, 2009).

When students engage in argument, they can understand more about the application of science and engineering which can benefit society through investigating phenomena, creating models, and resolving questions through data and evidence (NRC, 2012). One of the current challenges of researching argumentation practices is that there are a variety of different perspectives of the integration of argumentation within a science classroom (McNeill et al., 2017). Teachers' conceptions of argumentation practices may not always represent authentic scientific activity. If teachers did not learn science through argumentation, they may not know how to incorporate it effectively into their classroom (Henderson et al., 2017). Thus, there is a need to explore how teachers conceptualize scientific argumentation based on different frameworks and the unique characteristics of the teacher's' classroom context. This study will focus on exploring how Maine secondary school science teachers conceptualize the practice of scientific argumentation. In other words, our goal is to examine what aspects of scientific argumentation science teachers highlight and implement in their classroom based on their conceptualization of the practice. After a review of recent studies of argumentation in science classrooms, Manz (2015) recommends that the scientific argumentation should be more aligned with scientists' work if teachers intentionally embed argumentation activity in scientific uncertainty. Inspired by this review, we will look at how secondary school science teachers consider "uncertainty" when they explain their conceptions and implementations of scientific argumentation.

1.1. Purpose of the Study and Research Questions

For this study, we are interested in studying secondary school science teachers in the state of Maine. The state of Maine offers unique contextual characteristics which may influence science teachers' conceptions of argumentation and embedding uncertainty in school science. First, the NGSS, which highlight the importance of scientific practices, have been recently adopted as the official science standards in Maine (April 2019). Therefore, many schools in Maine are transitioning to NGSS during the 2019-2020 academic year which was the data collection timeline for this study. In addition, despite recent adoption of NGSS, some schools in the state locally started adjusting to NGSS and integrated the practice of Engaging in Argumentation from Evidence more intentionally in previous years. Second, Maine has the highest percentage (61.6%) of rural population in the United States according to U.S. census data collected in 2010 and therefore is the home to many rural schools. These rural schools tend to be economically less funded and the teachers who work in these schools have less opportunities to participate in professional learning activities due to long distances to travel or lack of reliable internet connection (Avery, 2013). The lack of resources in rural schools makes it harder for science teachers to collaboratively make sense of the ideas in NGSS. We therefore think that there is a need to look at how teachers make meaning of the ideas behind NGSS in the state of Maine. We are particularly interested in looking at Engaging Argument Based on Evidence practice. By analyzing survey data from 37 secondary school science teachers and interview data from a purposefully selected seven teachers, we aim to respond to the following research questions:

1. How do Maine secondary science teachers conceptualize the practice of "Engaging Students in Argumentation from Evidence?"
2. How do Maine secondary science teachers engage their students with uncertainty in science while using the practice "Engaging in Scientific Argumentation from Evidence?"

CHAPTER 2

LITERATURE REVIEW

2.1. Theoretical Background: Critical Thinking and Argumentation Practice

In this study, we see argumentation as one of the critical thinking skills that needs to be practiced in science classrooms. The ability to think critically provides many benefits, including more explicit understandings of problems and formulating richer and a wider variety of explanations (Kallet, 2014, p. 7). Building critical thinking skills takes practice and discipline, but developing this skill enables better decision-making, problem-solving, and creativity (Kallet, 2014, p. 20). The essential concept of critical thinking originates from "Socratic Questioning," where Socrates emphasized the importance of asking deep questions based on knowledge (The Foundation of Critical Thinking, 2019) and stressed the importance of empirical evidence and examination of assumptions and reasoning procedures. Through refinement of critical thinking analysis, the tools and resources of critical thinking have increased and folded into modern-day education. Through the history of critical thinking and the collective contribution of scholars, it is now possible to question the fundamentals of thought and reasoning.

By the 1970s, five different American philosophers served as a reference for how critical thinking is defined in education. Three of those philosophers are Robert Ennis, Richard Paul, and John McPeck. Robert Ennis referred to critical thinking as the ability to judge sources' credibility, identify reasoning, and drawing viable and credible conclusions (Daniel & Auriac, 2011). Like Socrates, Paul discusses the implications of ideal questioning in the development of critical thinking and reflective processes and defined critical thinking as, "the art of analyzing and evaluating thinking to improve it." (Paul & Elder, 2006). McPeck characterized critical thinking as the ability to engage in active and reflexive skepticisms to establish truths on what beliefs are based on (Daniel & Auriac, 2011). Using these different frameworks allows for greater flexibility when students are engaging in critical thinking. Below, the skill of critical thinking is discussed concerning how it is used in argumentation practices.

One of the essential critical thinking skills is argumentation. Engaging in argumentation requires both creative and critical thinking (Glassner & Schwartz, 2006). By engaging in critical thinking, one can develop logical opinions, which is a necessity to be an active member of a democratic society (Jiménez-Aleixandre & Puig, 2012. p. 1008). Jiménez-Aleixandre & Puig emphesizes how integrating argumentation in a school science can contribute and support the development of critical thinking. Since teachers are at the center of integrating argumentation in their science classrooms, they can help their students develop their critical thinking skills while engaging them in argumentation practices effectively. By providing students with the opportunity to build their skills in argumentation, their critical and complex thinking should be enhanced (Chowning et al., 2012, Sanders et al., 2009). The cognitive demand of critical thinking in scientific argumentation requires scientific reasoning skills between theory and evidence to address rigorous science topics (Hee-Sun et al., 2014). To improve critical thinking for argumentation practice, students must discern the difference between a weak and robust argument (Sanders et al., 2009). Improving in critical thinking skills can help students portray the knowledge and skills needed to formulate and evaluate an argument (Yacoubian & Khishfe, 2017). Geng (2014) researched the various definitions of critical thinking and found some of the following unanimous key terms: skills, questioning, problem-solving, and argument. The theoretical cognitive framework within which critical thinking resides provides a rationale for the conceptualization and utilization of engaging in argumentation from evidence. This is based on the work of Gass et al., (1990) who conducted a study comparing students who had completed a course in argumentation, and those who had not completed a course in argumentation. The findings of their study showed that argumentation instruction enhances critical thinking skills. The students who took the course in argumentation showed an enhancement in their critical thinking skills, which is characterized by their ability to discern weak argument, their decrease in verbal aggression when arguing, and self-reports of argument effectiveness (Gass et al., 1990). Based on the results of this study, researchers were able to conclude that the students that took the argumentation course could skillfully rebuttal and counter argue, enhancing their critical thinking.

Drawing from the critical thinking theory lens, we see argumentation as an important practice for students developing critical thinking skills such as learning to evaluate scientific evidence and the ability to make informed decisions as a scientifically literate citizen. Researchers noted teachers' roles as being pivotal in adapting argumentation to school science so that students can gain critical thinking skills (Chowning et al., 2012). Therefore, this study looks at how teachers make sense of argumentation practices for school science which can the help students to improve their critical thinking.

2.2. Conceptions of Scientific Argumentation for School Science

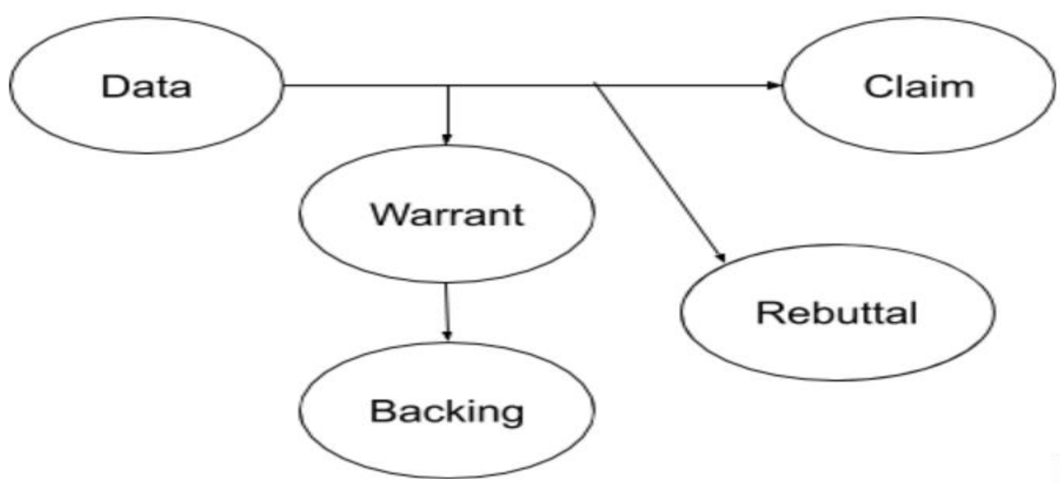
2.2.1. Scientific Argumentation Frameworks

There have been several different frameworks that conceptualize scientific argumentation practice; however, researchers have yet to agree upon what forms scientific argumentation practices (Manz, 2015). Previous studies in science education have been used to understand different frameworks of argumentation to get a broader understanding of the process (Sampson & Clark, 2008). The goals of argumentation are to make sense of scientific phenomena by analyzing the validity of claims and addressing the inconsistencies (Berland & Hammer, 2011).

Various scholars have cited three popular frameworks for scientific argumentation practice in science education: Toulmin's Argumentation Pattern model, Epistemic Levels of Argumentation framework, and Claim-Evidence-Reasoning (CER). While each framework is different, there is an overlap on how they conceptualize the practice of engaging in argumentation from evidence. Below is how each of the three frameworks contributes to argumentation, followed by the comparison and difference that can be deciphered between each of them.

2.2.1.1. Toulmin's Argumentation Model. Toulmin's Argumentation Pattern (TAP), published in 1958, has been the basis of scientific argumentation research for many science education scholars. Toulmin's framework suggests making context-dependent appeals based on data, warrants, backings, and qualifiers (Simon, 2008). Even though TAP could be used across disciplines, what qualifies as data, warrants, and the backing is field-dependent, making the model flexible in understanding and evaluating arguments. Based on Toulmin's (1958) book, *The Uses of Argument,* six main structural components of an argument were identified: claim, data, warrant, backing, qualifiers, and conditions of rebuttal as shown in Figure 1.

Figure 2.1 Toulmin's Argumentation Pattern



Data – This is what justifies the claim.

Warrant - The warrant shows how the grounds are relevant to the claims about the scientific argument.

Backing – The backing supports the warrant by showing how the warrant is relevant and related to the grounds and claim.

Rebuttal - These are represented in situations where the claim does not hold up.

Claim - Statement saying that something is so.

(Erduran et al., 2004, p. 918)

Osborne, Erduran and Simon (2004) studied how TAP could be used in argumentation. They found that using this model allows for a greater emphasis on examining the *process* of argumentation, opposed to focusing solely on the *content*. Using the six features highlighted in Figure 2.1, using the TAP model gave teachers in Osborne's study the ability to develop richer language which was an aid to their understanding of scientific disciplines (Osborne et al., 2004). Simon (2008) found in their research that the TAP model can be applied to written and transcript oral arguments to assess the complexity of an argument. The TAP model can help teachers assess student outcomes when engaging in argumentation and can provide students with the basis in evaluating their own arguments (Simon, 2008). Using the TAP model in the classroom is a useful tool for communicating and evaluating arguments when the six features of the TAP are used correctly.

Even though the TAP model can be a useful tool when engaging in argumentation, Osborne (2010) outline three limitations in Toulmin's argumentation model, (1) the structure of TAP does not evaluate the correctness, (2) dialogical structure is not considered in the TAP and

(3) linguistics and situation contexts are not emphasized (Driver et al., 2000, p. 294, p. 919). The challenge of analyzing verbal argumentation gave way to modification of the TAP by Kelly, Druker and Chen (1998) by classifying arguments by 6 claim dependent epistemic levels (Bogar, 2019).

2.2.1.2. Epistemic Levels in Argumentation. As mentioned above, when researchers Kelly, Druker, and Chen (1998) studied the TAP, they ran into limitations of the model that impeded the ability to assess verbal argumentation because of the difficulty in differentiating between the six components during discourse. Another difficulty teachers' have identified when using the TAP model in their classroom includes identifying claims, which stems from the ambiguity of the six TAP components during argumentation discourse (Simon, 2008). Using aspects of the TAP and Latour's Model (1987), Kelly, Druker, and Chen created six epistemic levels that are used for argumentation analysis (Kelly & Takao, 2001). The Latour Model elaborated on how argumentation is what scientists use to make their case for new ideas by moving from contingencies of their experiments to more generalized statements providing more abstract assertations of facts (Knorr-Cetina, 1995). These epistemic levels designed by are formulated in an inducted approach where claims start specific to a certain context and become more general to various situations. As shown in Figure 2.2, starting with Epistemic Level 1, the claims are specific to the problem's context. As the epistemic levels increase, the claims become more general. In the example provided in Figure 2.2 Epistemic Level 1, the oceanography propositions made by the student are specific to a contained geographical area, by epistemic level VI, the claims are generalizable to an area of study - in this case, oceanography. With each increase of level in the epistemology, it gets more general. Figure 2.2 outlines the epistemological levels based on the analysis of university oceanography students' use of evidence in writing. The outline of Figure 2.2 indicates the category of epistemic level, how it is defined in the oceanography context and examples of what the claim could look like during argumentation discourse.

Figure 2.2 Epistemic Levels for Analysis of Students' Scientific Papers: Definitions and Examples

Epistemic Category	Definition	Discourse Example
Epistemic Level VI	General propositions describing geological process and referencing definitions, subject-matter experts, and textbooks. The knowledge represented may not necessarily refer to data that is specific to the area of study.	"An oceanic divergent margin means that the plates, which form the Earth, meet and disperse in opposite directions."
Epistemic Level V	Propositions in the form of geological theoretical claims or models specific to the area of study.	"Continental convergent margins result in earthquakes because the subducting plate fractures under the stress and releases energy due to its folding below the subducting plate."
Epistemic Level IV	Propositions presenting geological theoretical claims or models illustrated with data specific to the geographical area of study.	"The sea floor, which is the Pacific Plate is subducted beneath the more shallow sea floor and island chain of the Eurasian plate."
Epistemic Level III	Propositions describing relative geographical relations amongst geological structure specific to the geographical area	"Shown in Figure 4 is the presence of over 60 volcanoes along the coast of the trench, reaching a distance inland approximately 230 km."
Epistemic Level II	Propositions identifying and describing topographical features of the geological structure specific to the geographical area of study	"Up to 10.5 km marks the deepest recorded depth within the trench which makes it the second deepest known trench in the world."
Epistemic Level I	Propositions making explicit reference to data charts, representations, locations, and age of island, or location the geographical area of study.	"The first particular area observed was found on the eastern coast of Asia (Figure 1)."

*(*Kelly & Takao, p. 322)

2.2.1.3. Claim-Evidence-Reasoning in Scientific Argumentation. Toulmin's model for creating an argument has been simplified into a more straightforward argumentation structure, Claim-Evidence-Reasoning (CER), for classroom use (McNeill & Krajcik, 2012). Due to the difficulties and limitations identified when using the TAP model Simon (2008), the framework was simplified to the CER framework. McNeill et al., (2006) defined each component of the CER framework as follows: claim, "an assertion of a conclusion that answers the original question (p. 158)." Evidence is defined as "scientific data that supports the claim; the data needs to be appropriate and sufficient to support the claims," (p. 158). Lastly, reasoning in the CER model is defined as "a justification that links the claim and evidence and shows why the data counts as evidence to support the claim by using the appropriate and sufficient scientific materials (p. 158)." The CER framework is more teacher and student friendly than the TAP, but it still provides an explicit, scaffolded instructional model that aids in creating more persuasive scientific arguments (McNeill et al., 2006; Berland & Reiser, 2008). While most teachers want to start incorporating CER practices into their classroom, they often have trouble in finding resources and curriculum materials designed to support them and their students when engaging in argumentation (Brown, 2009). Three challenges that have been identified for students when constructing CER arguments, 1) using appropriate and sufficient evidence, 2) constructing rebuttals and alternative explanations and 3) using scientific reasoning to rationalize why their evidence supports a claim (McNeill & Krajcik, 2007; Sampson & Blanchard, 2012).

2.2.2. Similarities and Differences of Argumentation Frameworks

The three frameworks discussed above are three of the more popular frameworks used in education with Toulmin's being the most historical, the Epistemic Level Argumentation framework being recently introduced into literature, and the CER framework as being the most utilized in a school setting (McNeill et al., 2006; Toulmin, 1958; Kelly et al., 2002). There are a few fundamental similarities in each of these three models. In the TAP and CER models the claim is the foundation and starting point when building an argument, and evidence is then built upon these claims to make sense of phenomena. This differs from the Epistemic Levels in Argumentation framework because an argumentation begins with evidence where claims are then built, generalized, and scaffolded based on the analysis of such evidence. This difference can be summed up in the location of where the claim falls in an argument. For the CER framework, it's at the very beginning of the argument, while in the Epistemic Levels framework and the TAP, it's at the end once the evidence has been analyzed.

2.2.3. Importance of Scientific Argumentation in the Classroom

Traditional classroom practices often follow a sequential three-fold process for discussion: teacher initiation of a question, student response to the question, and teacher evaluation of student response (McNeill & Pimental, 2010). This process rarely allows for student-to-student interaction and places the teacher in a position of power over students' learning. The Next Generation Science Standards (NGSS) suggest integrating eight science and engineering practices (SEP) that aim for students to be active agents in investigating scientific phenomena and construct scientific claims based on evidence through investigations, observation, and obtaining reliable resources (NGSS 2013). Scholars suggest that the shift to NGSS requires students' gaining epistemic agency (e.g., Stroupe, 2014; Miller, 2018) which Emily Miller (2018) defines as "students being positioned with, perceived, and acting on, opportunities to shape the knowledge building work in their classroom." Giving students the opportunities to construct their knowledge through scientific practices allows for students to explore and engage with scientific phenomena. As one of the eight SEPs from NGSS, the practice of Engaging in

Argumentation from Evidence can be effectively implemented if students take an active role while engaging in this practice. Ford (2012) discusses the process of argumentation as being a cycle of construction and critiques, where students construct their scientific knowledge through social interactions and through reflection on the reasoning of scientific phenomena. Manz (2015) found that when classrooms adopt a normative process for scientific argumentation, students developed a need to convince each other of their ideas which evolved into them backing up their claims, showing their evidence and justifying through reasoning. Students are more engaged in their participation of arguments when they are confronted with uncertainty in their knowledge, this can lead to prolonged discussion and investigation of targeted outcomes (Manz, 2015). Creating a classroom community that emphasizes the importance of argumentation, both written and orally, can promote scientific reasoning skills and conceptual understanding (Zohar & Nemet, 2002). Scientific argumentation gets students talking and gets them more involved with the material. Through argumentation practices such as debates, students must interact with the material and with each other directly. A classroom community that adopts scientific argumentation practices constructs student knowledge through evaluating, rebutting claims, and justifying acts while meaningfully engaging with material (Berland et al., 2015). Giving students that ability to participate in argumentation practices also allows for a social and dialogic process that allows students to strengthen their phenomena grounded in science (Faize et al., 2018). It has been proven that students that partake in argumentation practices have increased learning gains and have better retention of the concepts (Asterhan & Schwarz, 2007, 2009). To think like real scientists, they undergo the process of thinking and social interaction to build and evaluate arguments from their peers (Probosari et al., 2017). For this reason, a science classroom that adopts argumentation practices can promote students' social interactions, critical thinking, and retention of scientific concepts.

2.2.4. Challenges of Argumentation in Science Classrooms

Even though argumentation in classrooms allows students to learn and practice skills in a scientific setting, there are several challenges for both the teacher and the learner. A universal challenge exhibited across several scientific disciplines is defining what is meant by argumentation. For this reason, science educators must discuss the different frameworks and definitions of scientific argumentation and their applications in the classroom. Research has shown that several factors go into a teachers' instruction method, including learning goals and their conceptualization of how students learn science (McNeill et al., 2017). If a teacher has minimal exposure to practices such as argumentation, they may lack the confidence needed to integrate the practice into the classroom appropriately (Henderson et al., 2018). This lack of confidence can cause there to be fewer opportunities for students to engage in sensemaking activities when students are interacting with scientific phenomena (Sampson & Blanchard, 2012). In addition, teachers are facing challenges in finding a proper way to assess argumentation within classrooms (Henderson et al., 2018. According to the NRC (2012), "teachers need new tools and support to evaluate a range of students' responses in order to use that information to determine the next steps in their classroom instruction."

Students that lack prior knowledge on how to engage in argumentation or hold contradictory beliefs can have a hard time engaging in the argumentation practices (Faize et al., 2017). Not only is the lack of prior knowledge a challenge when engaging students in argumentation, Berland and Reiser (2009) have found that students struggle in differentiating between inferences and evidence when constructing their reasoning. Another possible challenge for students partaking in argumentation is if they are not cognitively developed enough to engage in abstract thinking, which is usually required when constructing and creating arguments (Kuhn, 1993).

2.2.5. Impact of Socioeconomic Status and Integration of Argumentation Practices

As mentioned above, there are a variety of challenges that teachers can face when integrating scientific argumentation practices. However, recent literature has found that schools that have a high percentage of students of lower socioeconomic status (SES) may face even more barriers when providing their students with the opportunity to engage in argumentation from evidence (McNeill et al., 2016). Jean Anyon (1980) analyzed the impact that social class has on school districts and found that districts of a higher social class had more teaching materials, supportive teacher services, and higher demands of student achievement. Anyon (1980) also found that schools of higher socioeconomic status had more opportunities to engage in critical thinking and creativity in the classroom, compared to schools of lower socioeconomic statuses, where correct answers and appropriate behavior were more prioritized than critical thinking and creativity. This limitation of student engagement with critical thinking can be attributed to more teacher-led instructional practices due to higher pressures to meet standardized test scores (Spillane et al., 2002). Teachers that work with students of lower socioeconomic status tend to feel an external pressure to meet state standards, so they often rely on lecture-style teaching to give information. Teachers, particularly those teaching in low SES schools, need more support in integrating cognitively challenging arguments (Katsh-Singer et al., 2016). Nearly half of the families in Maine, 41%, identify as low socio-economic status (National Center for Children in Poverty, 2018). For this reason, many public schools in the state of Maine identify as low SES, which can contribute to challenges have for effective implementation of argumentation

2.3 Uncertainty in Science and Science Classrooms

2.3.1. Uncertainty as an Important Aspect of Doing Science

Managing uncertainty is a fundamental component of science as scientists strive for certainty in scientific knowledge (Manz, 2015; Chen & Benus, 2019). Scientists encounter uncertainty when exploring explanations of phenomena and conducting experiences. Development of scientific practices for uncertainty goes through a cycle of construction, pushback, and refinement as scientists respond to feedback and the material world (Manz, 2019). In the modern-day, scientific uncertainties are often avoided in reports because of fear that audience members will distrust science (Maier et al., 2014). In a recent study looking at how communicating uncertainty affects public engagement with climate change, researchers found that uncertainty is often expressed to the audience in two ways: (1) evidence is lacking and conflicting and (2) reports may contradict each other (Maier. et al., 2014).

In scientific argumentation practices, the degree of uncertainty varies depending on the scientific investigation's limitations. A topic is deemed uncertain in science when the subject changes due to new scientific discoveries. Science topics can also be grounded in uncertainty if someone lacks the knowledge and skills to argue the specific scientific topic (Hee-Sun et al., 2014). Scientific argumentation can be used to untangle the complex web of uncertainty through supporting claims by using experimentation, instruments, and scientific concepts (Manz, 2015).

2.3.2. Uncertainty and Scientific Argumentation in Science Classrooms

There has been an increasing interest in science education research to look at scientific ideas or claims that includes uncertain aspects, as the scientific community is still building evidence on such topics. Most research in these areas have been studied under Socio-scientific Issues and Controversial Issues. Socio-scientific or Controversial issues (SSI) are issues grounded in science through topics that are controversial, socially relevant, and real-world problems (Barab et al., 2007). Examples of controversial issues in modern-day science include GMO crops, climate change, and genetic engineering. SSI are controversial because they tend to be complicated, open-ended, and may not have definite conclusions (Sadler, 2004), which can create uncertainty in the classroom.

Recent literature has found that integrating controversial issues into the classroom offers students the ability to engage with scientific phenomena actively and develop their argumentation skills (Osborne et al., 2004). For students to appropriately engage with controversial issues, they must be able to possess skills to create sophisticated arguments and avoid experimental bias (Kaptchuk, 2003). Research looking at the implementation of controversial topics pedagogical practices on student comprehension and how they make decisions have grown exponentially over the last 15 years. However, there has been minimal research on the crucial role that teacher's play in addressing these controversial topics (Saunders et al., 2011). Even though recent literature suggests integrating controversial topics into the science classroom, it has also been identified that adopting these controversial topics varies from teacher to teacher and, in some cases, this constrains the scientific curriculum (Berland, 2011). Some of these constraints that teachers face when integrating controversial topics in their curriculum include but are not limited to: teaching perception of controversial topics instruction, lack of controversial topics-orientated curricular materials, and limited support from administrators (Saunders et al., 2011). Teachers face other pedagogical challenges when integrating scientific argumentation practices, such as assessing the engagement of controversial arguments (Saunder et al., 2011; Tidemand & Nielsen, 2016).

Next Generation Science Standards (NGSS) emphasized the use of controversial topics such as climate change in classrooms (Hestness et al., 2016). Even though 42 out of the 50 states have started using NGSS in their school, there is no national science curriculum because each state is responsible for setting their educational standards. Because of this variation from state to state, there is much variation in the implementation of controversial topics in the classroom (Hancock et al., 2019). Some identified problematic concerns when students interact with controversial issues include their ability of making sense of data (Sadler, 2004 p. 542). This is because students are often relying on their intuition rather than argumentation skills (Acar O. et al., 2010). Specific problematic areas include students engaging with socio-scientific issues, including evaluating evidence (Iordanou & Constantinou, 2014), understanding the nature of science (Sadler et al. 2004), and scientific reasoning.

Even though most teachers see the positive impact of integrating controversy into their classrooms, they are often challenged with designing curricular assessments of their students' argumentation practice (Tideman & Nielson 2017). Levinson et al. (2011) identified that teachers tend to assess student knowledge through recall and memorization (Millar & Osborne, 1998). It is more difficult for teachers to interpret social implications, such as argumentation, as a measure of assessment. Tidemand & Nielsen (2017) found that teachers rely on summative assessments as a measure of student learning on topics related to the controversy, as opposed to formative assessments to measure their ability to argue.

2.4. Summary of the Background of the Study

A central goal of argumentation is students being able to articulate and make sense of science to support and refute daily interactions with scientific phenomena. Several of these interactions that students deal with in science are presented in various media sources such as new articles, social media platforms, and peer interactions. Many of these science topics that students interact with are open-ended with multiple solutions, making these topics controversial issues. Students must become exposed to these controversial issues through scientific argumentation to prepare them to be scientifically literate citizens (Owens et al., 2019). Students also deal with uncertainty in science class where they are integrating multiple scientific practices to make sense phenomena. Engaging in argumentation from evidence can aid students when dealing with uncertainty by carrying out investigations, debating claims, and building scientific reasoning through empirical evidence. It is essential to understand how teachers integrate both uncertainty and controversial issues into their science curriculums since there is so much flexibility in doing so. For this reason, we ask our second research question of how secondary science teachers engage their students in uncertainty in science while using the practice of 'Engaging Student Argumentation from Evidence?' In this question, we address uncertainty as an overarching term for topics in science that might cause from students' lack of background and experience in the argumentation process.

The contributions of this study will provide insight into the similarities and differences in how teachers conceptualize engaging in argumentation-based on the context of their disciplines, grade span, geographic location, resources, and NGSS alignment. Another contribution that can be made from this research is how teachers implement uncertainty in their classrooms. The literature identified the gap of research integrating uncertainty when students are engaging in argumentation from evidence.

CHAPTER 3

RESEARCH METHODS

A qualitative approach along with a frequency analysis was used to explore teachers' scientific argumentation conceptions and practices in Maine schools. This study was conducted in two phases, survey design and implementation followed by interviews with purposefully selected (Palinkas et al., 2016) teacher participants as exemplary cases for different types of conceptions and practices of argumentation. In this chapter, we will first remind the purpose of the study, followed by research questions. We will then elaborate on the participants, data collection strategies, and data analysis approach for each phase of our study.

3.1. Purpose of the Study

The state of Maine officially adopted the Next Generation Science Standards (NGSS) in April 2019. The mission of NGSS is to give students an in-depth understanding of content while students develop essential skills such as communication, inquiry, and problem solving (NGSS, 2013). The goal NGSS is for students to transition from the traditional *knowers of facts* to *doers of science* within the classroom (Miller et al., 2018). For students to take more agency in their understanding of science, NGSS standards encourages content learning along scientific practices and crosscutting concepts. As mentioned in the literature review section (Chapter 2), there are eight practices highlighted in NGSS, one of which is Engaging in Argumentation from Evidence. With Maine being new in its adoption of NGSS, it is crucial to study how these standards are being utilized and conceptualized in science classrooms. One purpose of this study is to understand how secondary science teachers conceptualize the practice of Engaging in Argumentation from Evidence. With this as the first goal in mind, one of the primary research questions is, "How do Maine secondary science teachers conceptualize the practice of “Engaging Students in Argumentation from Evidence”

The second goal of this research evolved as a focus during the first iteration of data analysis when teachers describe uncertainty as a challenging aspect of argumentation practice that they mostly want to avoid. Therefore, for our second research question, we aim to understand how teachers engage their students with uncertainty in science while they engage in scientific argumentation. Based on the literature, a science topic that is uncertain means that it is subject to change based on scientific discoveries. Using the practice of engaging argumentation from evidence can untangle these uncertainties for students by grappling with abstract science concepts to make sense of phenomena. With this being the second purpose of this study, we ask the research question of, how do secondary science teachers engage their students to uncertainty in science while using the practice of 'Engaging Student Argumentation from Evidence?"

By answering these two research questions, our goal is to understand how Maine secondary science teachers conceptualize the practice of engaging in argumentation from evidence and examine how teachers use uncertain science topics when their students engage in argumentation practices.

3.2. Phase One: Survey Design and Implementation

Phase 1 of the study used a survey distributed to Maine secondary science teachers to respond to the research questions of the study. We designed a survey with 32 questions that were expected to be completed in 15-20 minutes. The survey questions were on 1) teachers' demographics and NGSS alignment, and 2) conceptions and implementations of scientific argumentation. The survey consisted of both multiple-choice questions and short-answer essay questions. We initially formulated the questions inspired by the prior studies on argumentation (e.g., Henderson et al., 2018, Berland & Reiser, 2008, McNeill et al., 2006, 2018 and Osborne et al., 2004). These questions were then distributed among science education scholars and teacher educators for feedback. The revised version of the survey was piloted with two science teachers for final revisions. The questions on demographics asked about years of teaching experience, geographic locations, disciplinary teaching area, and grade span. Other questions asked survey participants to elaborate on their conceptualization of scientific argumentation by describing the practice in their own words, valuable resources, challenges, and implementation strategies. Below is a description of each type of question asked.

3.2.1. Multiple Choice Questions

The multiple-choice questions are split into three categories. The first type of multiple-choice question allows for survey participants to pick only one answer for the question or statement in the survey. The second type of multiple-choice question is a mesh between multiple-choice and written responses. Specific answer options to the question would have teachers explain themselves, for example if a teacher chose the option 'other,' they would be asked to write in a response. The third type of multiple-choice question allows participants to choose multiple answers regarding the question by asking them to select all that apply. The survey participants are asked either a question or given a statement, and they can pick as many options that apply to them.

3.2.2. Short-Answer Essay Questions

Survey participants were asked questions where they had to provide a short response. Some of the short-answer essay questions ask about necessary background information, such as what grade levels they teach, or the science discipline that they teach. Other write in responses ask teachers to explain in detail their thoughts about a question. On the survey, they were provided with a blank text box beneath the question to type in their answer, for example, “How would you define rigorous high-quality argumentation?” Three science education scholars and one scientist provided feedback on the initial draft of the questions. After we revised our questions per feedback from scholars, we piloted the survey with a high school teacher. Piloting the survey questions allowed us to understand how long the survey can take and make further revisions for the clarity of the questions.

3.2.3. Context of the Survey Study

The in-service teacher population of the study includes secondary science education teachers from schools across Maine. The only requirements to complete this survey were that the participants had to be a science teacher for grades middle school through high school in Maine (6-12th grade). Maine recently adopted the Next Generation Science Standards in April of 2019 for Maine public schools. Maine has 67.5% of the public schools identifying as rural (National Center for Education Statistics, 2013-14). A rural school is characterized by geographical isolation, population density, and overall school size (Johnson et al., 2014). Maine is unique with its new integration of NGSS, and it is a high percentage of rural school districts.

3.2.4. Participants of the Survey Study

Those invited by email to participate in the survey were connected through the Maine Science Partnership and researchers' connections. There were an initial 45 survey responses, but after going through the responses and removing the test-runs and blank surveys, there were a total of 37 participants. The other responses decided to skip some of the questions as the participation in each question was voluntary per *Institutional Review Board* guidelines.

Of the 37 Maine in-service secondary science teachers, demographics varied depending on years of teaching experience, geographical location, and adoption of NGSS as of the 2019-20 school year. Table 3.1 displays the frequency distribution of the demographics for the in-service secondary science teachers. As mentioned above, NGSS is a science curriculum that emphasizes more student engagement through Science and Engineering Practices when learning different scientific phenomena. When teachers are asked if their curriculum is aligned with NGSS, we are asking them how many of the skill and content standards they are integrating into their teaching. Teachers are also asked what their school demographics are: rural, suburban, urban, or other. Teachers answered these questions based on their perception of their school district population.

As is seen in the Table 3.1, the teachers varied in their teaching experience, although most of the participating teachers had either more than 20, or five to 10 years of experience. Moreover, most participants were teaching at high school level (grades 9-12) and identified their school location as rural.

3.2.5. Data Collection Procedures

An online survey was distributed via *Qualtrics,* a secure online platform, to collect data on these in-service secondary science teachers' implementation and conceptualization of scientific argumentation. Using Qualtrics allowed the researcher to collect responses anonymously and easily send reminders and thank-you emails to the participants. In-service teachers were given six weeks to complete the survey via Qualtrics. Working with the Maine STEM Partnership (MSP), the survey was distributed to teachers across the state of Maine via email, while other teachers were contacted with the survey through personal connections and relations to the researcher.

Table 3.1 *S*ummary of Teacher Survey Participant Characteristics

	Frequency	**Percentage (%)**
Years of Teaching Experience		
<5	5	13.90
5 to 10	8	22.22
10 to 15	4	11.11
15 to 20	8	22.22
20+	11	30.56
Grade Level Taught		
Middle School (6-8)	7	19.44
High School (9-12)	28	77.78
High School and College	1	2.78
School Demographics		
Urban	4	11.11
Suburban	9	25
Rural	21	58.33
Other	2	5.56
Is NGSS Required?		
Yes	21	56.76
In the process of adopting	5	13.51
Only required to use some standards	7	18.92
No	4	10.81

3.2.6. Data Analysis Approach

For the survey responses, a spreadsheet was created to look at trends for each question's responses. The spreadsheet contained 14 different sheets to organize the data for each question. The first sheet listed the teachers' names, pseudonyms, and willingness to participate in phase 2 (contextual information). The second sheet had all the recorded multiple-choice responses paired with the designated pseudonym. The third sheet contained all the questions with the 'other' option since it was a mesh between multiple choice and short answer responses. The remaining sheets each had one of the short-answer open questions paired with the participants' pseudonym and short-answer response.

3.2.7. Frequency Analysis of Multiple Choice Questions

Once the spreadsheet had all the participants' survey responses, it was categorized by frequency analysis. Using the Google Sheets, the frequency of each answer for each multiple-choice question was calculated. For example, for the question "How familiar are you with Engaging in Argumentation from Evidence?" participants could choose from the following options: extremely familiar, very familiar, moderately familiar, slightly familiar, and not familiar at all. For each option chosen by the participant, the frequency and percentage were calculated. For example, 18 survey participants said that they were very familiar with the practice of Engaging in Argumentation from Evidence, meaning that 48.6% of participants were very familiar with the practice. This process was done for every multiple-choice question.

3.2.8. Qualitative Coding for the Short-Answer Essay Responses

The process of coding for any of the short-answer questions was done through Constant Comparative Analysis (CCA), a process that analyzes qualitative data. The CCA method categorized codes based on what the research finds significant to the project's central focus

(Glaser, 1965). Taylor et al. (2015) summarize the process as "in the constant comparative method the research simultaneously codes and analyses data in order to develop concepts by continually comparing price incidents in the data, the researcher refines these concepts, identifies their properties, explores their relationship to one another and integrates them into a coherent explanatory model." (p. 126). I will go into further detail about how CCA was integrated into coding the short answer responses below. Using the deductive approach, we used our existing literature to come up with coding categories for each question; we then altered some of those codes based on the data collected from the survey. After several rounds of coding, we came up with parent and sub codes through a combination of an inductive and deductive approach.

Several questions in the survey were short answers where the teachers would be asked an open-ended question where they were required to create an explanation. Using Google Sheets, we aligned the pseudonym with their response, parent code(s), subcode(s), and comments. We came up with the parent codes from literature analyzing scientific argumentation practices. The different finalized subcodes came from the comparison and combination of the survey and interview. The table below gives an example of the question 'How would you describe the scientific practice of "Engaging in Argument from Evidence"?

Table 3.2 Examples of Coding Survey Responses

Pseudonym	'How would you describe the scientific practice of "Engaging in Argument from Evidence"?	Parent code	Subcode	Keywords and phrases
Samuel Reed	At our school this means students can support a claim using scientific evidence. Students can apply scientific principles and learning in their scientific reasoning. When available, students can include specific data in their scientific evidence.	Conceptualizing Scientific Argumentation	Use of reliable resources Integrating scientific reasoning Making sense of data	Support claim using empirical evidence Apply scientific principles Scientific reasoning Including specific data
Benjamin Young	Analysis of data and graphical results to build an argument that defends or refutes a hypothesis, confirms if this is supported by evidence that is either known or researched and the proposition of refinements that will further test the hypothesis if needed.	Conceptualizing Scientific Argumentation	Making sense of data Integrating scientific reasoning Communicating arguments	Analyzing data Defending hypothesis Refuting hypothesis Refining experiment Support claim using empirical evidence
Lindsay Howard	When students make claims based on the evidence that they have collected. (Or when they evaluate the claims of others). Students can question the validity of their results and the strength of their claim by thinking about how the data was collected, what the data means, and if enough data was collected to support the claims.	Conceptualizing Scientific Argumentation	Making sense of data Communicating arguments	Making claims based on evidence Questioning validity of claim Data collection Data meaning Data supporting the claim

This process seen in Table 3.2 was used for each of the participants' responses for each of the short answer questions. For each specific question, we used the first part of the CCA method to generate the keywords and phrases' theoretical properties to come up with categories (these could be considered as the grandchild codes). We then started integrating these grandchild code categories to come up with the subcodes. After several rounds of revisions and comparative analysis techniques, we calculated each subcode's frequency to the short answer question and graphed them by their frequency. In the following section, Findings, the graphs are explained by their representation of the subcode and frequency for each of the short answer questions that were analyzed.

3.3. Phase Two: Selected Teacher Interview

3.3.1. Preparing for Interviews

After coding and analyzing the survey data, we started conducting interviews with eight selected participants that completed the survey. When deciding the interviewees from the pool of survey participants, we determined the following criteria: their willingness to participate (a question in the survey), demographics, grade level taught, science discipline, and Next Generation Science Standards curriculum alignment. Ten people who were willing to participate in the interview were contacted via email and were given details about the interview protocol. Eight out of those ten contacted responded, saying they were willing to participate in the interview process. To get a variety of participant backgrounds, all eight of the interviewees differed in the criteria we were looking for. To assimilate similarities between interview responses, there were at least two of each criterion met from each of the eight interviewees. For example, at least two of the interview participants taught middle school, at least two were required to only do some of the NGSS standards, two taught in urban areas, etc. We only used seven out of the eight interviews to report our findings. After transcribing the eighth interview and looking at their responses, we saw that it did not align with the questions asked, which is why their interview was not included in the results. Below is a table showing the backgrounds of the seven interviewees.

Table 3.3 Characteristics of Interview Participants

Participants	**Years Teaching**	**Grade Level Taught**	**Demographics**	**NGSS Required?**
Lindsay Howard	15-20	9-12	Urban	No
William Cooper	10+	10-12	Rural	Yes
Anthony Wilson	20+	7-8	Rural	Only required to do SOME standards
Katherine Bailey	15-20	6-8	Suburban	Only required to do SOME standards
Andrea Turner	5-10	11-12	Rural	Yes
Sean Ward	5-10	9-12	Suburban	Yes
Jared Lee	15-20	9-12	Urban	Yes

3.3.2. Collecting Interview Data

Interview times were scheduled over email and took place from January 2020 to March 2020. Using the software Zoom, the interviews were done over a video conference call. The interview questions asked teachers to explain and discuss their answers in the survey. See pages 89 to 92 in Appendix B for the interview protocol. Each interview was recorded through the Zoom software and was converted into audio files, which were then uploaded to Descript, a transcription software. Using Descript, the entire conversation from the interview was transcribed and further edited to smooth out the interview. Phrases such as 'um' and repetition of the same word, for example, 'the the…. The students,' were translated into 'the students.' Cutting out stutters and words such as 'um' made for a more coherent transcription. Once every interview was thoroughly transcribed, the coding process began.

3.3.3. Analysis of Interview Data

Using Google Sheets, the interviews were organized by the turn of the interviewees. Each turn an interviewee completed was put into a cell. The process of breaking down the transcript into smaller units made it easier to categorize based on the parent codes. The transcription was then coded at the macro scale to determine initial parent codes and sub codes. We also included memos for each of our codes. For the interrater reliability analysis of the subcodes, two researchers first worked on an initial coding scheme. Each researcher assigned codes and subcodes separately to the transcripts of data from each in-service teachers' interviews. Then they compared the coding and discussed the title and the meaning of subcodes until they reached 100% agreement (Saldaña, 2015). Like the survey, coding took an inductive and deductive approach, where literature was used to formulate the parent codes and solidified the subcodes based on the survey and interview data. Below is an example of the layout of coding using Google Sheets.

Table 3.4 Transcription and Coding Examples from Interviews

Transcription	Parent Code	Subcode	Comments
Interviewer: So, what are the characteristics of high quality rigorous scientific argumentation in secondary science classrooms? *Anthony Wilson:* So, if they can explain the science behind something, and it's because of something that they learned, or if they've heard before and it's correct, then it's great. I do not like it when kids make an argument, or a statement based on that um a misconception. I still let them express how it is, but then being able to turn it back around. The problem with middle school kids is they hold on to those misconceptions… Also, we use a lot of the claim evidence and reasoning. Thursday, they have an independent experiment they must do for me where they must make a claim, they use the evidence, and then use the reasoning, for what happened.	Characteristics of argumentation	Use of prior knowledge Integrating scientific reasoning Making sense of data	Using what they have learned before to explain science behind concepts Holding onto misconceptions when exploring science concepts CER utilization for exploring science concepts
Interviewer: ...A high quality, rigorous scientific argumentation should look at the limitations of a claim based on the quality of the data.' And then you. Followed it up with a question, which I thought was awesome. Um, you said, 'do students think about whether or not the data is strong enough to support the claims?' Um, so would you like to add anything to this? And could you walk us through an example of this? High quality and rigorous argumentation? *Lindsay Howard*: So I think, um, I talked to my students a lot about... Before you can say that and have confidence or feel as though that's a reliable thing to like to	Characteristics of Argumentation	Using Multiple Scientific Practices Making sense of data	Making data strong Identifying controlling variable, constraints Eliminating experimenter bias Understanding limitations of investigation

Table 3.4 Continued

promote to other people. You know? What is it that makes your data strong? So, we talk about, you know, constants and controlling variables. We talk about what a control group can tell us. Um, we talk about, um, did you make an attempt to eliminate experimenter bias? So even with a really simple lab that I do at the beginning of the year with bubbles solution and whether or not adding salt or sugar will impact your ability to blow a bubble. So they just do this with a straw and then just soapy water. So, there's so much they have to control. Like what's the angle of the straw when they're blowing the bubble? Cause couldn't that be the reason why or how fast did they blow the air? Were you able to control that? Why or why not? So, does that limit your confidence?			

Excerpts from the interview are used to support the survey data of how teachers described the characteristics of scientific argumentation and how factors of uncertainty were utilized in their classroom. In the findings section, graphs show the frequency of codes for how teachers characterize the practice of scientific argumentation, which is supported by interview excerpts.

As described at the beginning of phase 2 of the study, the selection of teachers to be interviewed was based on their willingness to participate and varying attributes of the teacher such as their geographic location, the discipline they teach, grade span of their students, and their curriculum alignment with NGSS. Those characteristics were then compared with how teachers characterize scientific argumentation to determine if certain characteristics of argumentation could be accredited to the teacher's attributes.

Survey data was used to determine if/how factoring uncertainty was integrated into the practice of Engaging in Argumentation from Evidence. To develop a deeper understanding of how uncertainty was used, interview excerpts were used to analyze the variation of how teachers utilized the factoring of uncertainty.

3.4 Summary of Research Methods

The questions explored were 1) What are the ways do secondary science teachers conceptualize the practice of "Engaging Students in Argument from Evidence?" and 2) How do secondary science teachers engage their students to uncertainty in science while using the practice of 'Engaging Student Argumentation from Evidence?" To explore these questions, a study was conducted in two parts. The first part was distributing a statewide survey to secondary science teachers in Maine. The second part was to conduct interviews with some of the survey participants to explore claims that were made in the survey. Analysis of the survey was combined with the interview responses to explore these research questions. The next chapter explains the findings from the survey and interview excerpts.

CHAPTER 4

FINDINGS

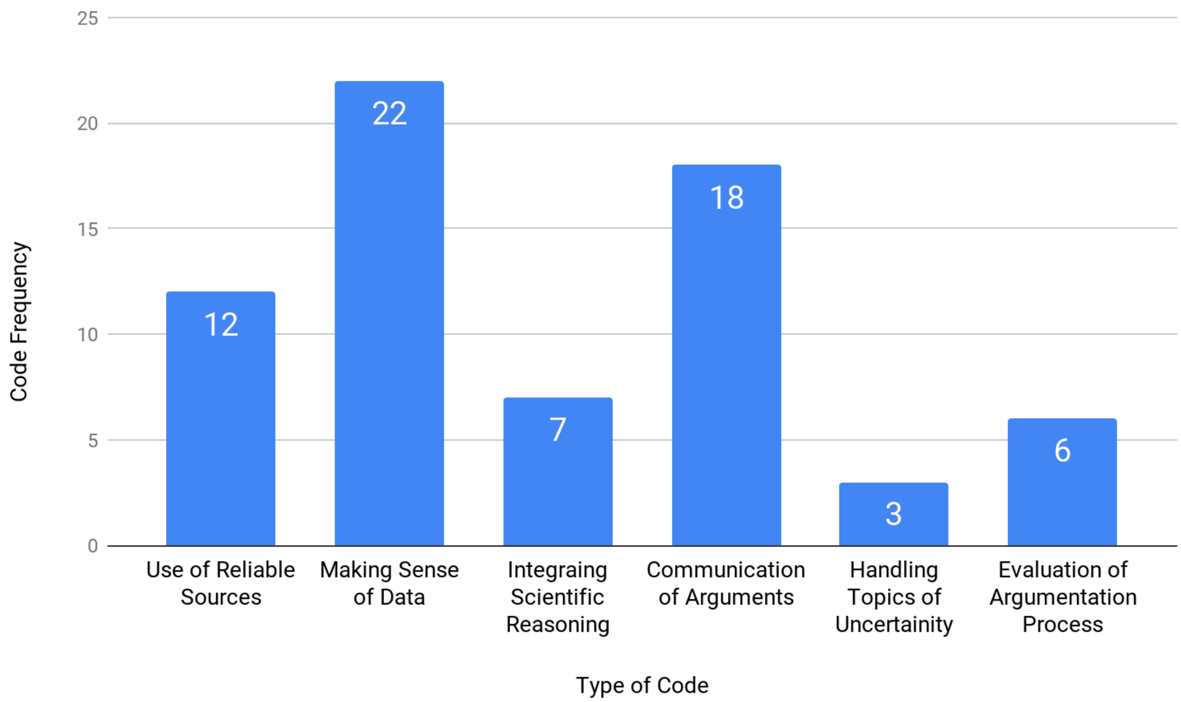
The first goal of this research is to gain insight into how Maine secondary science teachers conceptualize the practice of Engaging in Argumentation from Evidence. The second goal of this study is to gain insight on how uncertainty is integrated into their science curriculum while students are using the practice of Engaging in Argumentation from Evidence. With those two goals in mind, we ask the following research questions: "What are the ways do secondary science teachers in Maine conceptualize the practice of 'Engaging Students in Argumentation from Evidence?'" and "How do secondary science teachers engage their students to uncertainty in science while using the practice of 'Engaging Student Argumentation from Evidence?'"

4.1. Secondary School Science Teachers Conceptions of Scientific Argumentation

4.1.1. Aspects of Argumentation Highlighted in the Survey

To understand how Maine secondary science teachers, conceptualize the practice of engaging in argumentation from evidence, the survey data was coded to understand common aspects of scientific argumentation highlighted. For each code, the frequency analysis helped us determine what aspects of the argumentation practice were made salient by practicing teachers. Our constant comparative analysis showed the following six aspects of the argumentation highlight by teachers: 1) Use of Reliable Sources 2) Making Sense of Data, 3) Integrating Scientific Reasoning, 4) Communicating Arguments, 5) Handling Topics of Uncertainty, and 6) Arguing is a Foundation Skill. Figure 4.1 shows the results from the frequency analysis on each of these codes based on the survey data.

Figure 4.1 Frequency of Aspects of Argumentation Practice Highlighted by Teachers in the Statewide Survey

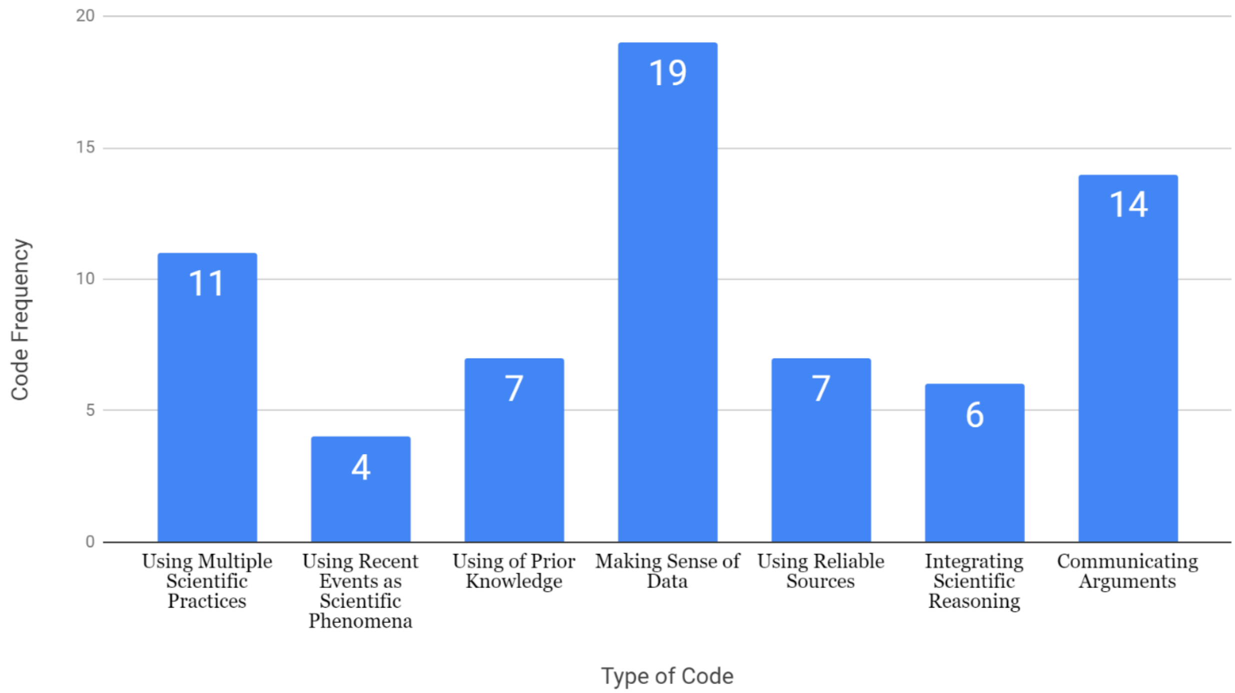


The codes in Figure 4.1 addresses how secondary science teachers in Maine perceived the practice of Engaging in Argumentation from Evidence. There was a total of 68 subcodes from the survey split into the 6 types of code. The code with the highest frequency (22 with 32.4%) is Making Sense of Data. Teachers' conceptions with this code represents how the argumentation practice is dependent on students utilizing data practices (such as graphing) during the argumentation process. Examples of how students make sense of data described by the teachers in the survey include using data to learn scientific concepts, and integration of data to support/refute claims. The second highest frequency code (18 with 26.5%) is Communication of Arguments that includes students' collaboration with peers to produce written and oral artifacts, and the norms and tools of communication that scientists use in the field when engaged in argumentation. Examples of this code include oral argumentation, lab reports, debates, and writing arguments. The code with the third-highest frequency is the Use of Reliable Sources (12 with 17.6%). Examples of this code from the survey include fact-checking, peer review, and evaluating reputable resources. The codes that were mentioned the least by teachers were Integrating Scientific Reasoning (7 with 10.3%), Evaluation of Argumentation Process (6 with 8.82%) and Handling Topics of Uncertainty (3 with 4.41%). Examples of the code Integrating Scientific Reasoning include explaining evidence and supporting their argument with reasoning. Examples of Evaluation of Argumentation Process include discerning flaws, critiquing argument and questioning the validity of claims and evidence. The last code, Factoring Scientific Uncertainty is represented by the examples of uncertainty caused by a student's lack of background or those caused by methodologically inherent uncertainties.

After teachers described the essential characteristics of scientific argumentation, we asked them which characteristics they want to see in high-quality student arguments. Although there were some similar aspects to essential characteristics such as the use of Reliable Sources for Evidence and Integration of Scientific Reasoning, there were also different characteristics highlighted by the teachers, such as Use of Prior Knowledge and Use of Multiple Scientific Practices. In response to survey questions, teachers described the characteristics of scientific argumentation. There was a total of 68 subcodes from the survey split into the 9 types of code. The Nine codes represent how the teachers characterized scientific argumentation. We noticed that the five of these codes with the highest frequency are also mentioned in the interviews. The top five codes with the highest frequency are Making Sense of Data (19 with 27.9%), Communicating Arguments (14 with 20.6%), Using Multiple Scientific Practices (11 with

16.2%), Use of Prior Knowledge (7 with 10.3%) and Use of Reliable Resources (7 with 10.3%). Examples of the Making Sense of Data from surveys include empirical evidence, quantitative data, and arguments that are data based. Phrases used to support the code Communicating Arguments from the survey include productive talk, listening carefully, and arguing from ideas grounded in science. On the other hand, we used the code Using Multiple Scientific Practices when participants talked about carrying out investigations and designing their experiments as an important step during the practice of argumentation. Use of Prior Knowledge is represented from the following survey data: integration of prior content knowledge, cross course materials, and application of knowledge. The following survey examples represent the code with the fifth-highest frequency, Use of Reliable Resources: use of reliable and, reputable resources, and learning a scientific citation style. The code Integrating of Scientific Reasoning is represented in the survey by teachers discussing the important of students using reasoning in their arguments. The code with the lowest frequency, Using Recent Events as Scientific Phenomena, is represented from survey responses such as, using current events to fuel argumentation and arguing over current scientific issues. Figure 4.2 shows how teachers characterized the practice of Engaging in Argumentation from Evidence based on the survey results.

Figure 4.2 Frequency of Aspects of High-Quality Student Arguments Highlighted



4.1.2. Example Cases for Teachers' Conceptions of Scientific Arguments from the Interviews

Due to the strong alignment between characteristics of an argumentation practice and what teachers seek high-quality arguments developed by students, we merged this question during the interview. The results from the analysis of the interviews provided further elaborations on the five characteristics of the argumentation practice. The following sections below elaborate on the five claims with the highest frequency; each one is supported by interview excerpts providing rationale and examples. In the excerpts, certain words and phrases are underlined to support the coding rationale.

4.1.2.1. Making Sense of Data. The code for Making Sense of Data represents how teachers expect students to use data to make sense of scientific phenomena when engaging in scientific argumentation. Examples of Making Sense of Data from the survey include using empirical evidence, data-based, evaluating evidence, and using multiple pieces of evidence. Out of the seven interviewees, all of them discussed Making Sense of Data as one of the characteristics of Argumentation. The following excerpt below came from Katherine Bailey's interview when she was asked about how she characterizes Argumentation,

> I always say to them, that to explain something you must provide specific evidence [that comes from data] and then tie it to the scientific reasoning. You know, once you make your claim, you must use evidence and scientific reasoning together to provide your answers.

When she talked about the characteristics of scientific argumentation, we categorized her response in this way with the following subcodes: Making Sense of Data and Integration of Scientific Reasoning. Katherine Bailey elaborated on how she integrates Making Sense of Data and scientific reasoning in the following interview excerpt:

> …Does the moon act alone, was the question. And so, the kids had to investigate this, if the moon acts alone. So, we did all these spreadsheets, you know, you get all this data, graphed all these spreadsheets. Then they had to create an argument that uses evidence from their spreadsheet that the moon did not act alone to cause the tides and they had to show…. And so then they can say based on that evidence, they can say that it is the sun and the moon that act together, the gravitational pull of the sun, the moon together creates those abnormally, creates the highest tides.

In the excerpt, Katherine Bailey walks us through how her students integrate, making sense of data in scientific argumentation when she has her students explore phenomena. In the example, she discussed how she has her students make sense of data by using spreadsheets, graphic organizers, and other forms of empirical evidence.

4.1.2.2. Communicating Arguments. During the interviews, teachers emphasized the importance communicating arguments between students and scientists alike. Some examples of Communicating Argument from the survey include debating claims, writing lab reports, and persuading through argument. Out of the seven interview participants, six of the interview participants discussed this subcode in their interview. In the following excerpt below, Jared Lee highlights the importance of persuasiveness in a written mode of communicating arguments.

> <u>Good science argumentation is the same as good as a persuasive essay structure </u>.And when I do my work really well, I use my <u>humanities colleagues' techniques</u> that my students have seen to make them <u>annotate and then work on text</u>.

Jared Lee sees using persuasive essay structure to develop written arguments and using the tool of annotation to collaborate on written argument.

Anthony Wilson below discusses how he gets his students to communicate arguments between students in the classroom:

> I use it [productive talk], I would say because of my knowledge of talk science or productive talk, that's allowed me to ask for building on to other students answers. So I'm all of a sudden, can somebody build on that? Can somebody cleared that up for me, I don't quite understand? there's a lot of different ways you can get kids to talk. I had this Nerf ball and throw that, throw that around and say, Oh, okay. If catch you catch the nerf ball did build on what somebody else just said, or do you agree with it or disagree with it?

In the excerpt above, Wilson discusses how students communicate when talking about science in the classroom. Wilson emphasizes he use of productive talk strategies which has his students build upon each other's arguments by clarifying and introducing new ideas into the argument.

4.1.2.3. Using Multiple Scientific Practices. The code with the third highest frequency, Using Multiple Scientific Practices (UMSP), represents how teachers have students create and conduct scientific investigations to explore concepts. Some examples of this code in the survey include collecting and analyzing evidence, writing procedures, testing scientific questions, and recording observations. Out of the seven teachers that were surveyed four of them discussed practices of their students using multiple scientific practices. These four teachers discussed and gave examples of students conducting labs, collecting their data, and refining experiments. Here is an excerpt of Lindsay Howard walking us through an example of how she has her students conduct scientific investigation by using multiple scientific practices:

> What is it that makes your data strong? So, we talk about, <u>contrasts and controlling variable</u>s. We talk about what a <u>control group</u> can tell us. Did you try to <u>eliminate experimenter bias</u>? So even with a simple lab that I do at the beginning of the year with bubbles solution and whether adding salt or sugar will impact your ability to blow a bubble, they just do this with a straw and then just soapy water, so there is so much they must control. Like what is the angle of the straw when they are blowing the bubble? Cause could not that be the reason why or how fast did they blow the air? <u>Were you able to control that? Why or why not? So, does that limit your confidence?</u>

Based on the walk-through example of how Lindsay Howard engages her students in argumentation, we coded the following excerpt with the following subcodes: empirical evidence, planning and carrying out investigations, and how scientists communicate. Since students oversee determining their control variables, constant variables, and the overall design of their experiment we assign UMSP as one of the subcodes.

4.1.2.4. Using Reliable Resources. The following subcode for scientific argumentation, the Using Reliable Resources, is how using credible sources is a characteristic of argumentation. From the survey, some examples from the subcode Using Reliable Resources include, research based, fact based, and using reputable sources. Out of the seven interviewees that were interviewed, four of them discussed the use of reliable sources. The following is an excerpt from Andrea Turner, where she is discussing the use of reliable resources along with an example of this practice of her students using these resources when participating in what Andrea Turner characterizes as argumentation:

> I still think it is important and especially, with kids, that they can find anything on the internet. And so that idea of still being able to look at, reliable and reputable, as a way of, are those sources, something that you really want to rely on?

In the excerpt, Andrea Turner discusses the implications of using reliable resources and their credibility. She continues to discuss the use of resources in the following example where her students practice analyzing resources through a New York Times article called the *.Org Mirage.*

> I just did in my environmental science class, we are doing a whole thing on, having them read, Silent Spring for example. And we talk about the concept of strong language and, what is using strong language and how do you evaluate a source. There was an article in New York Times about how really, like for example, we have been pounding these kids like the '.orgs' are really great websites. But, the truth, the article, it was the New York times, it is called the

> .Org Mirage, and it's about how really you can buy a .org, domain name. And so really, even just relying on that and having kids be automatically thinking like '.org' is, that is a good, reputable source.

When Andrea Turner was talking about the utilization of resources in scientific argumentation we interpreted as the Using Reliable Resources. Turner elaborated the ability of students to evaluate resources by understanding the use of strong language and citations within resources. She used the example of the New York Times Article *.Org Mirage* to explain how important it is for students to understand what makes a source for their argument reliable and reputable.

4.1.2.5. Using Prior Knowledge. The following subcode, Use of Prior Knowledge, represents how relying on prior knowledge is a characteristic of scientific argumentation. Based on the results from the survey a few examples that fall under the subcode of using prior knowledge, application of knowledge and claims based on scientific ideas. Out of the seven interviewees that partook in the interview, two of them discussed students integrating prior knowledge when engaging in argumentation from evidence. William Cooper discussed the importance of integrating prior knowledge when students construct argumentation. In the excerpt below, William Cooper characterizes the use of prior knowledge in argumentation:

> What an argument gains consists of, is you making a determination about an observation that you saw, right? There was an observation and you have to make a determination about what was responsible for that observation that you saw, but that determination can't be based on something whimsical, but determination has to be based on connecting two things. One is evidence and the other one is prior knowledge… We will be able to then create, what I am assigning is an argument. They are going to be able to come up

with an explanation invoking their evidence that connects to what I am calling the prior knowledge. When I say prior knowledge, the prior knowledge might be that, you know, this morning in the class, they found out.

In the excerpt, Cooper elaborated on two importance of creating an argument: evidence and use of prior knowledge. He then went on to elaborate that prior knowledge is any knowledge that you obtain leading up to an argument to explain the evidence. Based on what he said above, prior knowledge is foundational in students constructing argumentation.

While William Cooper discusses the importance of using prior knowledge, Anthony Wilson discusses how students can use their prior knowledge to hold onto misconceptions when Engaging in Argumentation from Evidence. In the following excerpt below, Anthony Wilson discusses how students use their prior knowledge to hold onto misconceptions when explaining scientific phenomena:

> So, if they are able to explain the science behind, and it is because of something that they learned, or if they've heard before and it's correct, then it's great. I do not like it when kids, make an argument, or a statement based on a misconception… The problem with middle school kids is they hold on to those misconceptions. Even if you show them that a block of wood with a hole in it will still float, well, you are doing something wrong. It should sink. And they still hold on to that. And even sometimes when you get my tests or assessment at the end, they hold on misconceptions even though they have been proven that, no, that is not the way it is, because they still held onto misconceptions.

Even though Cooper and Wilson discuss the use of prior knowledge as a characteristic of scientific argumentation, they look at prior knowledge in two different ways. Cooper looks at prior knowledge as being science content that you learn and applying it to reasoning, while

Wilson looks at how prior knowledge rooted in scientific misconceptions can lead students astray when exploring science.

4.1.3. Similarities of Interview Responses and Teacher Background Information

Using the five highest frequency codes for the characteristic of scientific argumentation, common attributes of interview participants are highlighted based on their characterization of scientific argumentation. Similarities could include geography, discipline, grade band, argumentation resources and NGSS alignment. Below, Table 4.1 lists the teachers and common attributes that were compared across teacher participants.

Table 4.1 Comparison of Argumentation Characteristics to the Contextual Characteristics for Each Teacher

Teacher	Argumentation Characterization Subcode	Resources of Argumentation	NGSS Alignment	Geographic Location	Discipline	Grade Band
Katherine Bailey	Use of reliable resources Use of Multiple Practices Making Sense of Data	NGSS Website Online Blogs Textbooks	Only required to use some standards	Suburban	Physical Science STEM Gifted/Talented Life Science	6-8
Sean Ward	Use of reliable resources Integrating Scientific Reasoning Communicating Arguments Making Sense of Data	Graduate studies Samples of student work Content Specific Labs	Yes - aligned with NGSS	Suburban	Honors Physics Engineering Robotics	9-12
William Cooper	Integration of Scientific Reasoning Use of Multiple Practices Connecting to Prior Knowledge Use of Recent Scientific Events	Conference (RiSE) Training in research field Colleagues Past Career	Yes - aligned with NGSS	Rural	Honors Biology AP Biology	10-12

Table 4.1 Continued

	Making Sense of Data Communicating Arguments					
Lindsay Howard	Use of Multiple Practices Use of Recent Scientific Events Communicating Arguments Making Sense of Data	Workshops (Talk Science, content immersion) Professional Development Courses (Making Student Thinking Visible)	No - not aligned with NGSS	Urban	AP Chemistry Honors Chemistry CP Biology	9-12
Anthony Wilson	Making Sense of Data Communicating Arguments Integrating Scientific Reasoning Use of Prior Knowledge	Conference (RiSE) Professional Development Groups (Maine Physical Science Partnership, RiSE Center)	Only required to use some standards	Rural	Life Science Physical Science Computer Science	7-8
Andrea Turner	Use of Reliable Resources Communicating Arguments Use of Multiple Practices Making Sense of Data	Previous Field Experience	Yes - aligned with NGSS	Rural	Chemistry Biology Physics	11-12

Table 4.1 Continued

	Integrating Scientific Reasoning					
Jared Lee	Communicating Arguments Making Sense of Data Integration of Scientific Reasoning Use of Reliable Resources	Personal Research Online Videos (YouTube)	Yes - aligned with NGSS	Urban	Oceanography Physical Science STEM	9-12

4.1.3.1. Similarities for Making Sense of Data. Out of the seven teachers interviewed, all teachers discussed Making Sense of Data as being one a characteristic of scientific argumentation. There is no one similarity that connects all the teachers, besides them teaching secondary education science in Maine.

4.1.3.2. Similarities for Using Multiple Scientific Practices. Four of the seven teachers discussed Using Multiple Scientific Practices (UMSP) as being a characteristic of scientific argumentation. The four teachers include: Katherine Bailey, William Cooper, Lindsay Howard, and Andrea Turner. One commonality for all four of them, is their disciplines they teach or have taught. They all have taught some form of life science including Biology, Oceanography and General Life Science. A commonality between William Cooper, Lindsay Howard, and Andrea Turner, is that they all teach at the high school level and teach a variety of different leveled courses including honors and AP.

Another commonality between Katherine Bailey, William Cooper, and Andrea Turner, is that they all are required to integrate some if not all the NGSS Standards.

A characteristic that connects all four of these interviewees is their teaching of more academically advanced students that are in honors, AP, or gift/talented classes. Using Multiple Scientific Practices is a more complex skill for students to do and tend to be more for academically stronger students. Students that are academically stronger tend to be enrolled in the honors, AP and gifted/talented courses which could give these teachers more opportunity to participate in UMSP practices.

4.1.3.3. Similarities for Communicating Arguments. Four out of the seven interviewees discussed the importance of communicating arguments when engaging in scientific argumentation. This communication is represented by both how scientists and students communicate arguments. The code for communicating arguments includes strong language, persuasion, and discussion of scientific topics. The four interviewees that discussed this aspect of argumentation communication include Sean Ward, Lindsay Howard, Jared Lee, and Andrea Turner all of which teach grades nine through 12. All four of them teach courses within physical science including chemistry, physics, and engineering.

4.1.3.4. Similarities for Using Reliable Resources. Four out of the seven interviewees discussed how a characteristic of scientific argumentation is the using reliable resources when formatting argumentation. The teachers that discussed using reliable resources in their interview include Katherine Bailey, Sean Ward, Lindsay Howard, and Andrea Turner. All four of these teachers teach a course within a physical science discipline including physics, chemistry, and engineering. Three out of the four (Sean Ward, Lindsay

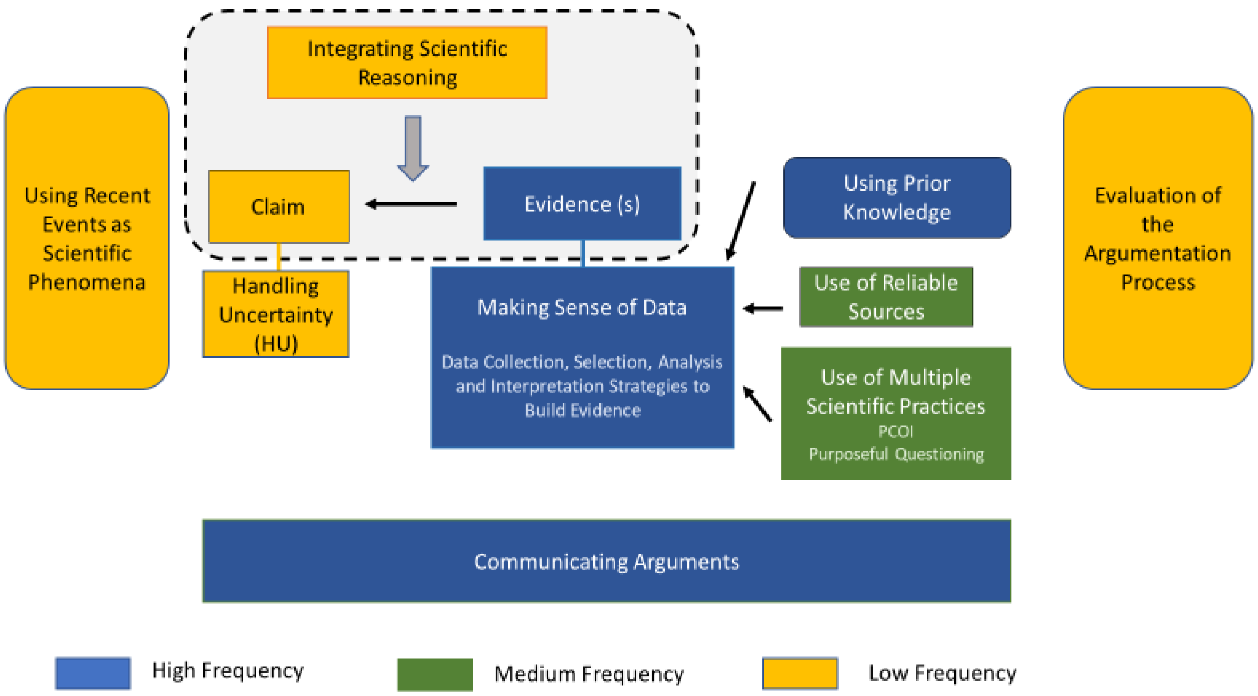
Howard, and Andrea Turner) are high science teachers that teach within the grade span of 9th-12th grade.

4.1.3.5. Similarities for Using Prior Knowledge. Two of the seven teachers discussed Using Prior Knowledge as being a characteristic of scientific argumentation. The two teachers that discussed the use of prior knowledge are William Cooper and Anthony Wilson. A commonality between these teachers is their rural geographical location and RiSE workshops for formatting their conceptualization on scientific argumentation characteristics. Rural locations tend to be more conservative when addressing socioscientific issues (Maxwell, 2019) which can feed into misconceptions in science.

4.1.4 Summary of Highlighted Aspects of Argumentation Practice by Teachers

The Figure 4.3 shows what aspects of argumentation are highlighted by the teachers. The figure is color coded to represent how often these ideas was discussed during the interviews. Blue shows highly frequent aspects (more than 50% of subcodes), green shows a medium frequency (25-50% of subcodes), and yellow shows low frequency (less than 25% of subcodes). Since we worked with teachers, it made sense for us to have a focus on CER framework and within this framework, evidence was the most mentioned components. When teachers talked about evidence, they focus on the need to make sense of data to have stronger evidence. For teachers, the way to make sense of data depend on 1) using prior knowledge, 2) use of reliable sources, and 3) using multiple scientific practices. Integrating scientific reasoning, on the other hand, was not brought up by many teachers. This might be due to challenges of students and teachers have in understanding reasoning component of the CER framework (Berland & Reiser 2009). Another mostly mentioned aspect of the argumentation was the way students learn to communicate arguments either through collaboration with peers or recognizing the way scientists effectively communicate arguments. Rarely, couple teachers highlighted the importance of Handling Uncertainty (HU) while providing opportunities for students to discuss counter-claims. Other rare topics discussed were: Using Recent Events as Scientific Phenomena to engage students in the argumentation practice and the evaluation of the argumentation process

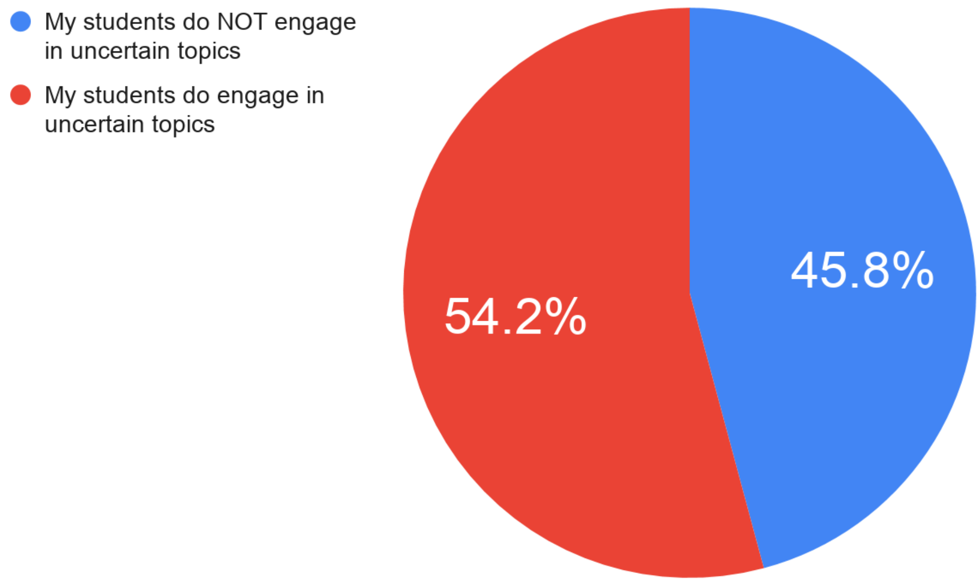
Figure 4.3 Summary of Highlighted Aspects of Argumentation Practice by Teachers



4.2. Addressing Uncertainty in Science Classrooms

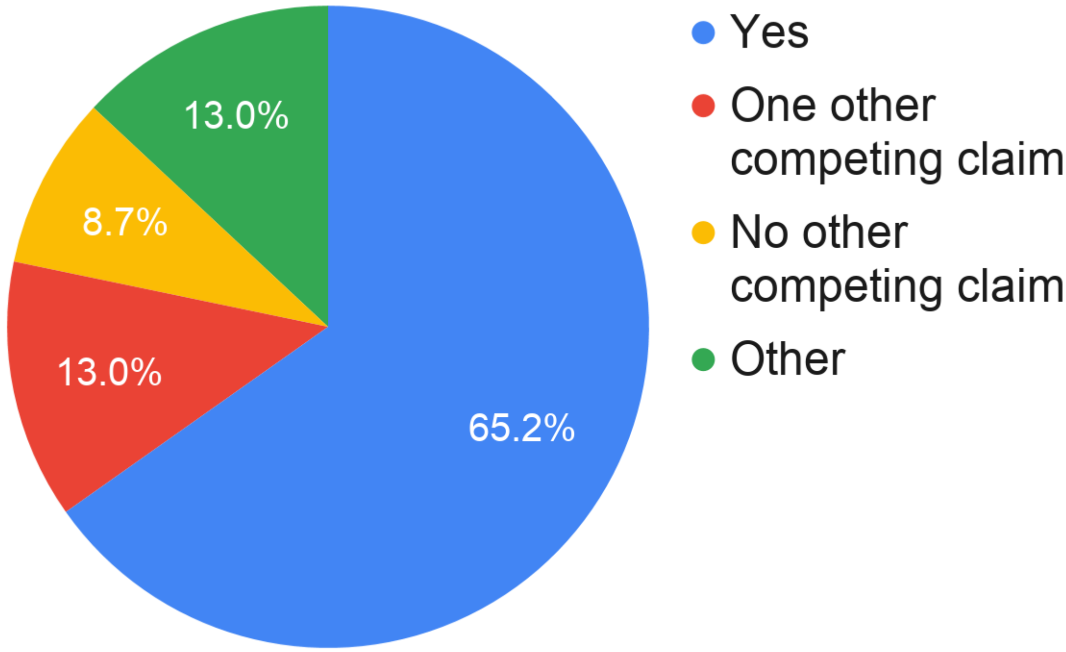
To address the research question for how secondary science teachers, engage students in uncertainty, survey data and interview transcripts were used to show how uncertainty varies and is utilized within the classroom. Figure 4.3 contains survey data asking participants if they allow their students to engage in argumentation from evidence for certain topics only.

Figure 4.4 Percentage of Teachers that Engage their Students in Uncertainty in the Statewide Survey



About half of the teachers who participated in the interview said that they only engage students for certain topics. The participants that said yes, they only engage in certain topics only, provided rationale for doing so. Reasons included: time restraints, utilizing uncertainty only in labs, and using uncertainty only for debates and for discussing controversial topics. The next question in the survey asked if they allowed for competing claims when their students engage in argumentation from evidence. Figure 4.4 shows the percentage of teachers who allowed for competing claims, did not allow for competing claims, or only allowed one other competing claim.

Figure 4.5 Percentage of Teachers Allowing for Competing Claims in Argumentation from Statewide Survey



About two-thirds of the teachers surveyed said that they do allow for competing claims, roughly 10% said they do not allow for competing claims and 13% indicated that they start off with competing claims, but eventually come to consensus and only use one claim. The two survey participants that said no, they do not allow for competing claims, teach Anatomy & Physiology, Biology, Chemistry and Life Science. For the 13% of participants that said other, they were able to write-in what they meant by choosing the option of 'other'. Examples of what teachers said when they chose 'other' included that using competing claims depends on the topic, another example is only using competing claims when there is allotted time to do so since including more claims took up more class time.

In the interview, we asked the seven participants about their integration of uncertainty when having their students engage in argumentation from evidence. Based on the interview responses, there were three different interpretations of what an uncertainty was: 1) uncertainty is dependent on marginal error which can be calculated through different statistical tests, 2) uncertainty indicate that the answer is not known beforehand and 3) uncertainty is controversial topics meaning that there could be a disagreement on a certain topic. Below are three different excerpts from survey participants highlighting their conceptualization of uncertainty:

4.2.1. Measurement Uncertainty

Measurement uncertainty can be defined as a dispersion of possible values where within that range lies the true value (Possolo, 2019). Below is an excerpt from Sean Ward, where he explains that uncertainty is based on statistical analyses and describes it as an annoying calculation:

> ...whereas uncertainty is just an annoying calculation because you have, let's say your meter stick is accurate within one millimeter, you're going to measure within an uncertainty of one millimeter. So now you have that, and you know that the mass was uncertain within a 10th of a gram. So, you have got to take your one millimeter and multiply it times a 10th of a gram and plus or minus that, that at the end there. And that is your uncertainty for your thing. And it is that mathematical component just adds another level of difficulty.

Based on the excerpt, we interpreted how Sean Ward described uncertainty as a statistical error included in students' calculations when analyzing measurements. Ward is also a physics and engineering teacher that has his student actively collect data in a lab setting when exploring different physical topics.

4.2.2. Uncertainty in Students' Knowledge

Below is an excerpt from William Cooper, where he explains that uncertainty is when the student does not know the answer beforehand, even if there is one correct answer. For the student, the content may be uncertain because they have not been exposed to the science yet, even though the biological process is certain in science.

> At least with my students in the CER because when they do a CER almost always or generally there is only one answer, and I still consider it an argument. The reason why I am comfortable calling an argument is because I am convinced that they are not confident…. When it is not black and white, then there might be reasons why when the answer is not obvious, they have to go ahead and take data. And then, you know, build a response explaining why that is right. Then to me, that takes on the role of argument. So even if there is only one right answer, if that right answer is not just like the same, everyone is not going to take the same obvious linear path that you could say in one sentence. The question, 'how come the plants in the dark didn't grow?' And you know, like everyone is going to be like, well, because I did not get any light. You've known since you were not in second grade. That is not, that's not argumentation. The plants that did not have carbon dioxide did not float. That is something that is not necessarily a pathway it is laid out for them. They must think about that. So, if they are not engaging them in critical thought, I do not think it can be an argument whether or not that they have something wrong or not.

In the excerpt, William Cooper describes how uncertainty is when the answer is not obvious, and therefore the students must engage in critical thinking to formulate reasoning. In his example, William Cooper discussed a lab where students have to investigate why some plants are not growing in different environments is considered an argument for a few reasons: 1) students have to collect data and build a response based on their data 2) the students have to engage in critical thinking to explain the scientific process and 3) the answer is not 'black and white' to the students.

4.2.3. Methodological Uncertainty of Controversial Science Topics

Controversial topics, also known as socioscientific issues (SSI), are topics that are open ended with multiple answers. Below, Lindsay Howard elaborates on how uncertainty is part of the integration of SSI topics in the classroom when engaging in argumentation:

> The year I did the climate science unit... I think I focus more on the science, like their mode of hailing circulation, and how that brings thermal energy from the equator up to the Northern parts of the Atlantic? And why is that a good thing? We do not want to be in an ice age. Oh, but why are the polar ice caps melting changing the circulation and, yeah, so it was very focused on the science and not enough of uh, we're doing this we need to think about that a little bit more. I think it is easy to shy away from these hard topics, I think.

Howard is discussing the use of a popular controversial issue, climate change, which is a topic where understanding and opinions greatly vary. Howard elaborates by discussing that these topics can be difficult to address in the classroom, so they must be deep rooted in science in the presentation of the content. While the science and evidence may be universal, the outcome of student perception and answer could be different between students.

4.3. Summary of Findings

There were a variety of ways that Maine secondary science teachers described the practice of Engaging in Argumentation from Evidence. As mentioned in the literature, there is no one unanimous definition of engaging in the practice of scientific argumentation and we saw that with the data, where there were several different ways aspects and characteristics identified by participants. Excerpts that were used to support the survey data were cross examined to see if there were any relations between how scientific argumentation was described and the demographics of the participants. We saw that similarities in geographic location, discipline, grade band taught, and argumentation resources corresponded to how survey participants conceptualized the practice of engaging in argumentation from evidence. A surprising finding was how uncertainty in argumentation varied in its use when students participated in argumentation. As described in the excerpts above, there were three different perspectives of what it means to integrate uncertain science topics in the classroom 1) measurement uncertainty, 2) uncertainty in students' knowledge and 3) controversial issues. Finally, across all interviews, all the participants remarked how making sense of data is an important aspect of engaging in scientific argumentation from evidence. It was the only characteristic that was universally mentioned from every interviewer and had the highest frequency in figures 4.1. and 4.2.

CHAPTER 5

DISCUSSION

This study focused on one of the eight Scientific and Engineering Practices in NGSS (2013), Engaging in Argument Based on Evidence Argumentation practices in science classrooms are an important component for building students' critical thinking skills. With Maine having a high rural school district population and the recent integration of NGSS, it is important to understand how argumentation practices are being used by these secondary science teachers. The purpose of this thesis was twofold; to understand the ways secondary science teachers in Maine conceptualize the practice of "Engaging Students in Argumentation from Evidence" and to understand how Maine secondary science teachers engage their students in uncertainty while using the practice of "Engaging in Argumentation from Evidence."

Analysis of the results on the first research question, "What are the ways do secondary science teachers in Maine conceptualize the practice of "Engaging Students in Argumentation from Evidence?" revealed what teachers highlight as crucial characteristics of scientific argumentation in school science. Maine secondary science teachers identified Making Sense of Data, as one of the important characteristics of scientific argumentation followed by Communicating Arguments.

Analysis of our results from our second research question, "How do secondary science teachers engage their students to uncertainty in science while using the practice of 'Engaging Student Argumentation from Evidence?'" indicated some of the teachers considered scientific uncertainty as a part of argumentation practice.

Our in-depth interviews showed that the meaning of uncertainty among teachers has varied. There were three different ways of how Maine secondary science teachers incorporated uncertainty in the classroom (1) measurement uncertainty, (2) uncertainty in student knowledge and (3) controversial issues. Next, current literature is discussed as it applies to this research study further to identify the possible implications for Maine secondary science teachers. The major points include: (1) identifying critical aspects of scientific argumentation, (2) the use of Multiple Scientific Practices when engaging in argumentation, (3) how to communicate arguments, (4) how to include productive uncertainty in the classroom and (5) distinction between explanation and discussion.

5.1. Making Sense of Data is Universally Highlighted by All Teachers

The first discussion point is how the results of this study support the idea that Making Sense of Data is a key characteristic of scientific argumentation. In the Maine statewide distributed survey, secondary science teachers were asked what aspects went into the practice of "Engaging in Argumentation from Evidence," with the most frequent code response was Making Sense of Data. Consequently, another question in the survey asked the participants to characterize the practice of "Engaging in Argumentation from Evidence," where the most frequented code was once again Making Sense of Data. Excerpts from interview participants were used to provide context and further explanation of how scientific argumentation is characterized. Out of the seven interviewees, all of them discuss Making Sense of Data as a key characteristic of "Engaging in Argumentation from Evidence." Since Making Sense of Data was the number one coded frequency as a characteristic of argumentation and was a universal theme among all interviewees, it shows the importance of students making sense of data when they engage in argumentation.

Research on classroom implementations of scientific argument has emphasized the importance of not only integrating data but also making sense of data by using mathematical practices (Lehesvuori et al., 2017, Aberdein, 2009, and Forman et al., 1998). As supported by our findings with excerpts and frequency coding, teachers in Maine see making sense of data as essential when students engage in argumentation from evidence. By engaging in sense making when formulating arguments, students develop a deeper level of conceptual understanding instead of just memorizing facts (Berland & Reiser, 2009). For students to support the grounds and claims they make in argumentation, they must be able to make sense of data (McNeill et al., 2006). For this reason, a suggestion could be made about math and science teachers working together to help students increase students' ability to make sense of data through mathematics. Using math is important when making sense of data, because it helps students determine the relationship between data and a constructed explanation (Keenhold, 2019). According to *Science for All American,* it is recommended to have learning goals in the classroom that promote scientific literacy to become more aware of the ways to connect science, math and technology depend on one another as a way to develop scientific knowledge (Hurts, 2015). In the classroom, the process of sense-making of data can occur when students are working on interpreting graphs and analyzing the alignment of claims and evidence (Berland & Reiser, 2009).

In addition, teachers can help students build authentic claims by guiding their use of real data sets. There are several data portals developed for K-12 classrooms to help students integrate real data sources into their argumentation practices. Two resources teachers can consider are CoDAP (CoDAP, 2020) and Tuvalabs (Tuva Labs Inc., 2020, which provide students with research-based data, graphing, and tools so they can explore, manipulate, and make sense of the data). CoDAP provides resources for students to gather data, but it also provides a Community for Educations to collaborate and connect By providing students with the opportunity to engage with resources such as Tuvalabs and CoDAP, students will be able to build on their argumentation skills while activity making sense of data. In this study, teachers also discussed using mathematical skills such as graphing and statistical analysis to make sense of scientific concepts through data.

5.2. Learning to "Communicate" Arguments is an Essential Aspect of the Practice

Another essential characteristic of "Engaging in Argumentation from Evidence" highlighted in our findings is how arguments are communicated. Teachers highlighted the aspect of *Communication of Arguments,* where it had the second-highest code frequency in Figure 3.1. Similarly, *the Communication of Arguments* had the second-highest code frequency in Figure 3.2 based on how participants characterize the practice of argumentation. The code, Communication of Arguments, represented how both scientists and students communicated through argumentation; this included lab reports, debates, and sharing results. For scientific information to be passed on, we must communicate through argumentation practices. It is important to communicate in science for several reasons: it builds support for science, encourages more collaboration, and encourages more innovation for future directions in scientific research (Feliu-Mojer, 2015). When students take on the communicative role of scientific argumentation, they can access a deeper understanding of scientific activities (Manz, 2015). As outlined in the survey results, many participants identified the communication of arguments as one of the main characteristics of scientific argumentation. Secondary science teachers must foster a safe classroom environment where students can assimilate their arguments to scientists and encourage collaboration to develop a deeper understanding of scientific phenomena.

For students to communicate their arguments like scientists, they must be allowed to engage in argumentation. Meyer (2014) provides insight for reconstructing the learning classroom environment for increase communication: (1) engaging students in scientific questions, (2) providing opportunities for students to respond to questions with evidence, (3) encouraging students to formulate explanation from evidence, (4) encourage students to communicate and justify their findings. Berland L., Reiser B., (2019) describes the practice of scientific argumentation as, "a social practice in which members of a community make sense of the phenomena under study proffering, evaluating, critiquing, challenging and revising claims through discourse." Based on how Berland and Reiser described engaging in argumentation, and Meyer's insight for classroom reconstruction, it is apparent that communication between students, the teacher(s), and science is essential in making sense of phenomena.

Several researcher findings suggest that social construction of scientific argumentation through communication has been beneficial to students understanding of scientific phenomena; however, several studies have found that secondary school science lessons tended not to include activities that support argumentation and the social construction of knowledge (Newton P., Driver R., Osborne J., 2000). Based on these findings, I suggest including more opportunities for students to engage in communicating arguments through debates, scaffolding practices, and literacy practices. A resource that can help teachers understand discussion protocols of science in the classroom is *Talk science* through the *Inquiry project*. This online or in-person professional development helps teachers foster productive and effective science talk and communication in their classroom (The Inquiry Project, 2011).

5.3. English Language Arts (ELA) Integration to Science Classrooms can Create Opportunities to Learn How to Communicate Scientific Arguments

Another highlighted characteristic of scientific argumentation from one of the interviews was students using persuasion as a tool for communication arguments. Jared Lee discussed using his humanities colleagues, such as the social studies and language arts teachers, as advisors to help him find ways to integrate tools of persuasion for when students are formulating and communicating their arguments. In most traditional classrooms, we see a more authoritative style of speech upon the teacher's delivery of content. Authoritative discourse in the classroom assumes that students will accept the teacher's word without much consideration of how it fits in with what is being taught (Berland & Hammer, 2011). Contrary, Cornelius L. & Herrenkohl (2004) discuss another form of discourse that can occur in the classroom that focuses students building their own knowledge. *"Persuasive discourse* allows for the recipient of a message to accept the speaker's word in part and compare it with his or her knowledge." (Bakhtin, 1981). Below I will discuss how the Next Generation Science Standards call for the integration and opportunity of English Language Arts (ELA) when students engage in scientific argumentation.

While the NGSS Framework was being developed, the NGSS development team and the Common Core State Standards (CCSS) development team worked together to identify literacy practices in building knowledge in science. This collaboration between NGSS and CCSS ensures that science does not work in isolation by bridging literacy and the Scientific and Engineering Practices. CCSS discusses the implications of scientific literacy in the classroom including understanding the nature of evidence, attention to detail, synthesizing complex information and capacity to assess arguments (Common Core State Standard Initiatives, 2020). The Science and Engineering Practices in NGSS integrate CCSS Literacy Anchor Standards to promote scientific literacy when developing scientific arguments (NGSS, 2013).

Based on the research findings and the NGSS collaborative framework with CCSS, working with ELA standards can help students with their argumentative writing. Teachers can work with their humanities colleagues to help students create more persuasive and literate scientific arguments. Scientific arguments built on scientific literacy can lead to higher quality arguments; this can be accomplished through the collaboration of science teachers and humanity teachers working together.

5.4. Use of Multiple Scientific Practices Reflects Authentic Work of Scientists

Another trend that was apparent both in survey data and interview excerpts is the use of Multiple Scientific Practices (UMSP) when creating arguments. The UMSP reflects on how teacher participants used multiple Science and Engineering Practices from NGSS when implementing scientific argumentation in the classroom. A common science and engineering practice that teachers mainly discussed was Planning and Carrying Out Investigations (PCOI) as a critical prior step to gathering information. In the survey, teachers discussed their students creating experiments, critiquing evidence, collecting data, and analyzing evidence as a characteristic of a more high-quality scientific argument. What is interesting in this finding is that for scientific argumentation to take place, teachers tend to integrate other practices such as Asking Questions and Defining Problems, Analyzing and Interpreting Data, and Developing and Using Models. The Scientific and Engineering Practice, Constructing Explanation and Designing Solutions were discussed from the teacher participants as part of Engaging in Argumentation from Evidence, as opposed to it being its own practice.

As mentioned above, one of the eight NGSS scientific and engineering practices that were highlighted by the teachers is the practice of Planning and Carrying out Investigations (PCOI). Duschl (2014) emphasizes that by giving students, step-by-step procedures anticipated when conducting investigations strips away students' cognitive demands. Providing students with PCOI opportunities within the classroom enables rich opportunities for discussion and engagement to occur since the practice pushes for students to make decisions by formulating questions, collecting data, and making explanations (Duschl & Bybee 2014, NGSS Framework, 2012). In order to help students actively engage with the material when using argumentation practices in the classroom, teachers must be able to incorporate multiple scientific practices such as designing investigation, asking questions and constructing explanations (McNeill & Knight, 2013). McNeill et al., (2016) grouped the eight practices into three practices: *Investigating Practices, Sense-making Practices,* and *Critiquing Practices.* To make sense of the natural world, students must be able to integrate the three groups of practices to make persuasive arguments, this finding suggests that arguments must incorporate multiple Science and Engineering Practices from when "Engaging in Argumentation from Evidence."

Based on our findings and the previous research, I suggest that when teachers engage their students in argumentation from evidence, they incorporate many scientific and engineering practices. To make sense of the science, they [teachers] must incorporate an investigation practice to collect data and make sense of models/explanations. For further research in using multiple scientific practices, I would look at how each of these three practices (investigating, sense-making, and critiquing) is utilized in the classroom to make sense of science. Research has found that teachers integrate Investigating Practices into their curriculum regularly; however, there is less support and fewer resources for integrating Sense making Practices; for this reason, future research must look at supports for integrating Sense Making Practices.

5.5. Integration of Uncertainty in Scientific Argumentation Practices

When teachers were asked if they integrate certain topics only in their science curriculum, about half of them answer yes, they only allow certain topics. Our findings also indicate that a third of the participants do not allow for competing claims in their classrooms. When interviewees were asked to elaborate on how uncertainty was integrated into their science curriculum, we were surprised by the different perspectives' teachers took when exploring uncertainty. Teachers conceptualized uncertainty in three different ways: (1) measurement uncertainty, (2) controversial uncertainty, and (3) lacking prior knowledge during scientific exploration. Below I will further discuss the implications and future directions of integrating uncertainty into science classrooms.

5.5.1. Measurement and Methodological Uncertainty

In our findings, there were three different conceptualizations of what it means to engage students in uncertainty. One of the conceptualizations of uncertainty was measurement uncertainty. which is defined as "a parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurement." (Mimi 2020). The interviewee that discussed measurement uncertainty looked at it from the perspective of a range of values attributed to student and instrument error. Another way that teachers conceptualized uncertainty was through controversial issues, which are relevant real-world issues that have multiple solutions. Some examples mentioned by participants include global warming, genetically modified organisms, and genetic engineering. Below I will discuss how productive uncertainty can be included in the science classroom and its implications on student learning.

In Stephen Gardiner's (2011) *A Perfect Moral Storm: Climate Change, Intergenerational Ethics, and the Problem of Moral Corruption,* he discusses the controversy behind the ethical implications about the complex phenomenon of climate change. There is a significant amount of uncertainty when addressing climate change; because of this, there is a lack of systemic regulation of how to control factors affecting climate change. This can be due to the lack of trustworthy evidence and the complexity of the hypothetical situation. Because of the complexity and consequences of addressing climate change head-on, we tend to turn a blind eye to not only solving issues of greenhouse gases but neglecting the impact it has on people, industries, and the commonwealth. Gardiner discusses how covering up the uncertainty of climate change has caused a shift of intergenerational ethics, causing procrastination in addressing issues as vast as climate change. Manz (2019) provides insight into how science teachers can incorporate uncertainty into their science classrooms, to combat this issue of sweeping uncertainty under the rug. In her study, Manz (2019) found that teachers need more professional development support when incorporating uncertainty into student learning. Professional development opportunities can provide crucial elements of uncertainty as a pedagogical construct including (1) designing complex situations that provide opportunities for students to grapple with the NGSS practices, (2) maintenance of dealing with complicated phenomena and (3) providing students strategies to share ideas when partaking in these practices. Chen et. al (2019) uses these three stages of argumentation as a way for students to productively manage uncertainty in the classroom: raising, maintaining and reducing. The first stage, *raising,* refers to students asking question and establishing a need for understanding. The second stage, *maintain,* is the students' ability to deepen understanding through prolonged discussion. The last stage, *reducing,* is synthesizing ideas based on the discussion and addressing inconsistencies of the argument. Using these three stages of argumentation, students can develop a deeper understanding of how to use students' epistemic understanding of argument through social negotiation.

Based on the literature and the findings, it is apparent that teachers are confused in understanding how to integrate uncertainty into a science curriculum. While there is confusion about integrating uncertainty, this study also highlights the importance of uncertainty when students Engage in Argumentation from Evidence. For this reason, I suggest providing more professional development opportunities where teachers learn how to conceptualize uncertainty and integrate it into their curriculum. Providing students opportunities to engage with uncertainty through argumentation will help them make sense of real-world problems and develop a deeper understanding of scientific topics.

5.5.2. Uncertainty and One Accurate Scientific Claim

A second perspective from one of the teachers' participants was that uncertainty can still exist even when there is only one accurate claim due to the current state of student knowledge. The example elaborated on in this teacher's interview discussed how students participate in scientific labs where they do not know the result of a certain scientific phenomenon. While there is only one correct explanation of what the students observed, the topic is still considered uncertain because the students do not have the background context to explain the phenomena. The teacher further explained how the students constructed their knowledge over several weeks of the unit, and eventually were able to demonstrate the knowledge they needed to create explanations of that specific phenomenon.

As discussed through literature, argumentation seeks to justify scientific claims through critical evaluation of empirical evidence. However, researchers have questioned if there is a necessary distinction between explanation and argumentation when students are creating and justifying scientific claims. Osborne & Patterson (2012) argues that argumentation differs from an explanation because explanation seeks to increase in the construction of knowledge. While there is a distinction between the two, there is also confusion in how these two different epistemic practices are used in the classroom. Osborne (2011) argues that there must be a clear distinction between these two practices since they have two very different goals in the science classroom. When students are constructing explanations in the classroom, they are asked to explanation their observations based on their knowledge. Comparatively, when students are asked to engage in argument, they construct the link between an explanation and the known data

(Osborne & Patterson, 2012). The goal of argument is to persuade or convince, while the goal of explanation is to comprehend scientific phenomena. In response to how Osborne deciphered the difference between these two practices, Berland & McNeill (2012) provided possible education strategies to respond to the overlap of explanation and argumentation. The work of scientists involves asking question, developing models, constructing explanations and engaging in argument, for this reason these it is argued that explanation and argument do not happen in isolation (Berland & McNeill, 2012, Osborne & Patterson, 2011) . Naming these two different practices would allow for students to engage in these different practices, however other researchers argue that it's more important to focus on the big picture rather than the individual components within scientific inquiry (Ford, 2006). Using argument and explanation in a science classrooms allows for students to build their knowledge and construct explanation for scientific phenomena; constructing explanation allows for students' and scientists to them to make sense of evidence, while argument allows for the scientists' and students to improve their explanations (Berland & McNeill, 2012). Teacher participants that took part in the interviews did not distinguish between explanation and argument as they used the terms interchangeably. As mentioned in the Use of Multiple Scientific Practices, there are usually multiple science and engineering practices incorporated in making a scientific argument, for this reason, Berland and McNeill suggest that scientific inquiry is more significant when students are looking at the holistic phenomenon rather than individual components such as the separation of practices.

As mentioned throughout the study's findings and literature, teachers have difficulty integrating and designing science activities grounded in uncertainty. As discussed by one of the interviewees, topics are still considered uncertain if the students lack the prior knowledge needed in the explanation of the phenomena. For this reason, I suggest that students can be exposed to studies that have one right answer and still be engaging in uncertainty because they lack the scientific knowledge to understand the reasoning behind it.

5.6. Limitations of the Current Study

There are three limitations to this study. The first limitation is the small sample size that we used to explore how science teachers make meaning of the scientific argumentation. Because of time and funding restraints, only a limited number of interview participants partook in this study. Such limited samples, on the other hand, allowed us to conduct more in-depth analysis examples provided by teachers on various aspects of argumentation. The second limitation was methodological as we relied on teachers' explanations of their classroom context and how they embed uncertainty in scientific argumentation. Further research on how teachers attend to scientific uncertainty can design classroom observations to gather field notes or video data to analyze the actual classroom practice. The third limitation is due to inconsistent definitions of rural by the census bureau, we choose to label the schools based on how teachers label their schools' geographic location.

5.7 Summary of Discussion

The goal of this study was to understand how Maine secondary science teachers conceptualized the practice of scientific argumentation, and how they embedded uncertainty in the scientific argumentation practices. Because of the unique characteristics that the state of Maine offered in this study – new integration of NGSS and high percentage of rural school districts, there was no unanimous conceptualization of scientific argumentation and uncertainty.

Overall, survey participants highlighted *Making Sense of Data, Communicating Arguments* and *Using Reliable Resources,* as aspects of argumentation. Survey participants additionally highlighted *Using Multiple Scientific Practices* and *Integrating Scientific Reasoning* as aspects of high quality scientific argumentation. Conducting interviews with selected survey participants provided insight on how uncertainty was integrated when students were Engaging in Argument from Evidence. There were three different ways that uncertainty was integrated from the seven interview participants: *measurement uncertainty, students lack of prior knowledge* and *methodological uncertainty.*

The results of this study provide implications for integrating scientific argumentation and uncertainty including 1) mathematic teachers and science teachers working together, 2) providing multiple different ways for students to communicate argument, 3) utilizing humanities colleagues and their techniques as a way for students to construct written arguments, 4) using multiple scientific practices when students are engaging in arguments and 5) providing students with the opportunity to grapple with uncertainty through argumentation practices. Future studies could expand on this project by providing resources for integrating uncertainty and studying the conceptualization of scientific argumentation to a larger spectrum of teachers.

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APPENDIX A

SURVEY ON "SCIENCE TEACHER'S CONCEPTIONS AND IMPLEMENTATION OF SCIENTIFIC ARGUMENTS"

Informed Consent

Q1.

Thank you for your consideration in participating in my research study. My name is Erin Doran and I am currently a graduate student in the RiSE (Research in STEM Education Center) at the University of Maine, pursuing a master's in science teaching. With my faculty advisor, Dr. Asli Sezen-Barrie, I am working on a research about how scientific argumentation is used in secondary science classrooms. My hope is that an understanding of teacher perception and implementation on scientific argumentation practices may inform professional development activities for teachers and the development of resources to support classroom practice. Please read this form and ask any questions you might have before you agree to take part in this research.

What You Will Be Asked to Do

You will be asked to participate in an online survey on Qualtrics (an online survey tool supported by the University of Maine). Online surveys will take place at your convenience and will last approximately 15-20 minutes. You will be asked a series of questions about your background and your use of scientific argumentation. No advanced preparation is needed. It is completely ok if you are not using scientific argument argumentation in your classrooms as this information will also be useful for our study.

Risks

The only anticipated risks to you are the time and possible inconvenience involved in participating in the study.

Benefits

There are no direct benefits to the participants. However, the findings of the study are useful for science teachers in understanding their argumentation practices in science classrooms. As these practices are part of the new science standards, teachers will have benefit in learning how other teachers utilize argumentation practices. The findings of the study will be shared with all participants.

Confidentiality

The teachers will initially put their real names. Once the surveys are completed, the data will be downloaded onto a password-protected computer that is only accessible by me and my advisor, Dr. Sezen-Barrie. The teachers participating in this survey will be de-identified by using pseudonyms. and the key containing the surveys will be destroyed by August 1, 2021.

Voluntary

Your participation is entirely voluntary. Should you choose to participate, you may withdraw at any time without consequences of any kind. The information you provide in this survey will not impact any of your relationship with the University of Maine or related professional learning programs.

Questions about the Study

If you have questions or concerns during the time of your participation in this study, or after its completion, you would like to receive a copy of the final summary of results of this study, please contact: Erin Doran at erin.doran@maine.edu or Dr. Asli Sezen-Barrie, Faculty Advisor at asli.sezenbarrie@maine.edu.

Questions about Your Rights as a Research Participant

If you have any questions about your rights as a research participant, please contact the Office of Research Compliance, University of Maine, 207/581-2657[3] (or e-mail umric@maine.edu)."

Would you like to participate in this study?

a. Yes

b. No

Q2. Which one of the following best describes the location of your school?

a. Rural

b. Suburban

c. Urban

d. Other (Please explain)

Q3. How long have you been teaching science?

a. Less than 5 years

b. 5 - 10 years

c. 10 - 15 years

d. 15 - 20 years

e. 20 + years

Q4. What grade band do you typically teach?

Q5. What science course(s) do you currently teach (Include AP (Advanced Preparation), Honors, Gifted and Talented (GT)?

Q6. How familiar are you with NGSS (Next Generation Science Standards)?

a. Extremely familiar

b. Very familiar

c. Moderately familiar

d. Slightly familiar

e. Not familiar at all

Q7. Did your school adopt NGSS (Next Generation Science Standards)?

a. Yes

b. I am not sure

c. No

d. Our school is in the process of adopting

e. We are only required to use some standards from NGSS (Please provide examples)

Q8. Is your curriculum aligned with NGSS (Next Generation Science Standards)?

a. Ye

b. I am not sure

c. No

d. We are planning to align our curriculum with NGSS during the next year or two

Q9. How familiar are you with eight "Scientific Practices" outlined in the NGSS?

a. Extremely familiar

b. Very familiar

c. Moderately familiar

d. Slightly familiar

e. Not familiar at all

Q10. How familiar are you with the scientific practice of "Engaging in Argument from Evidence"?

a. Extremely familiar

b. Very familiar

c. Moderately familiar

d. Slightly familiar

e. Not familiar at all

Q11. How would you describe the scientific practice of "Engaging in Argument from Evidence"?

Q12. What are the characteristics of high quality, rigorous scientific argumentation in secondary school science classrooms?

Q13. Have you ever been in a workshop, conference, or a course where you learned about engaging students in argument from evidence?

a. Yes, more than five times

b. Yes, three or four times

c. Yes, once, or twice

d. No

Q14. What was the most valuable workshop, conference, or course for learning about engaging students in argument from evidence? Please explain.

Q15. Other than the professional learning environments and resources you used, what are some experiences that shaped your understanding of what it means to engage in scientific argumentation based on evidence? (These experiences can be related to your interactions with students, colleagues, scientists or from your daily life)

Q16. What is your most valuable resource (textbook, book, journal, website, etc.) for learning and teaching about engaging students in argument from evidence? Explain how resources help you and your students?

Q17. Why is it important to engage your students in argument from evidence in your science classroom(s)?

Q18. What challenges do you face while engaging your students in argument from evidence in your science classroom(s)?

Q19. Do you feel that there are gaps in your understanding of what it means to "engage students in scientific argumentation"?

a. No, I have a well-established understanding of the practice

b. Yes (Please explain what these gaps are and what would you need to improve your understanding)

Q20. How often do your students engage in argument from evidence in your science classroom(s)?

a. Every Day

b. Once a Week

c. Once a Month

d. Once a Semester

Q21. Does the frequency of engaging students in argument from evidence vary depending on students or classes you teach? Please provide an explanation for your answer.

Q22. What is your typical level of guidance while your students are engaging in argument from evidence in your science classroom(s)? (You can choose multiple options for this question if you need)

a. I provide students everything they need to be able to communicate their scientific arguments

b. I provide students with claim and scientific reasoning and expect them to collect the data for evidence to respond to the claim

c. I only provide students with the scientifically accurate claim and ask them to collect data for supporting evidence and make connections to scientific principles

d. I provide a scientific question and expect students to figure out claims, collect data for supporting evidence and make connections to scientific principles

e. Other (Please explain how)

Q23. Do you believe that all your students and classrooms need a similar level of guidance while they are engaging in argument from evidence?

a. Yes

b. No (Please explain how you would differentiate guidance among students with different needs)

Q24. Do you engage students in argumentation for certain topics only?

a. No, we use argumentation in all the science topics

b. Yes, I use argumentation only for certain topics (Please list these topics)

Q25. Do you have your students engage in arguments about controversial or debatable topics such as evolution, vaccinations, climate change, etc.?

a. Yes

b. Sometimes

c. No

Q26. What are the strategies that you believe are effective for helping students engage in argument from evidence? (You can choose multiple options in response to this question)

a. Claim - Evidence - Reasoning (CER) Framework

b. KLEWS (Know -Learned - Evidence - Wonder -Scientific Principles)

c. Whole Class or Group Debate

d. Other (Please Explain)

Q27. For the strategies you chose in the above question, explain your rationale for why you believe these strategies are effective.

Q28. Do you allow for competing claims in your science classroom(s) while you engage your students in argument from evidence?

a. Yes, my students work with competing claims all the way through the scientific activity/unit

b. I attend to competing claims at the beginning of the scientific activity, but then we collect our evidence on the most accurate claim

c. I rarely design activities that allow for competing claims in my classroom(s)

d. Other (Please Explain)

Q29. Would you be willing to participate in an extensive version of this study where you will be interviewed for 45 mins via zoom? The participants will receive a $25 stipend.

a. Yes

b. Maybe if I have more information

c. No

Q30. First and Last Name:

Q31. Frequently Used Email:

Q32. School Name:

APPENDIX B

INTERVIEW PROTOCOL

Interview Protocol - Scientific Argumentation

Hi, my name is Erin Doran, and I am a graduate student at The University of Maine through the Research in STEM Education program. I am conducting research on the extent to which scientific argumentation is conceptualized and used in the classroom. I am interested in how scientific argumentation is being utilized, what resources you may use, and what obstacles you have faced when teaching argumentation. I will be using these surveys this interview for later transcription and coding, but your responses will be de-identified. This interview will take approximately 45 minutes and will be recorded; remember that this interview is voluntary, and you choose not to answer a question, and stop the interview at any time. Do you have any questions before we start the interview?

Their Curriculum /Standards and Using Arguments

1. You mentioned the use of NGSS………….at your school. What school curriculum do you use?

2. How much flexibility do you have in changing/ revising or writing activities within your curriculum?

3. How are scientific argumentation activities built into your curriculum? Can you walk us through a typical example?

Teachers' Resources of Arguments

You mentioned that you utilize ……… sources. Can you elaborate on how those resources are? How did they help you?

If it is a professional development, what did the learning environment look like? Do they have continuous support or collaborations following the face to face or virtual professional development activities?

Examples of High Quality Arguments vs. Low Quality

You described the characteristics of high quality arguments as………. Would you like to add anything else?

Can you walk us through an example?

How do you assess the quality of arguments in your classrooms?

Scaffolding in the Classroom

How do you help your students to learn to communicate high quality arguments?

What are some strategies and tools do you have?

What do you expect from your students?

Using Argument Differently vs. Similarly Based on Context

Option 1: You said you use the argumentation practice differently for ……………………. What are the challenges for bringing all students to the same level?

What support would you need to be able to help create an environment where all students are learning argumentation practices at the same level?

Option 2: You said you use the argumentation practice similarly for all students. What individual differences exist among your students? What helps you to be able to bring the same expectations?

Uncertainty

What are the benefits and/ or challenges of exposing students to uncertainty in scientific arguments?

Option 1: You said that you use argumentation practice for uncertain topics. Can you give us examples of topics for students' arguments that integrated uncertainty?

Option 2: You said that you do not use argumentation practice for uncertain topics. What are some of the obstacles and challenges you believe you would have if you tried to integrate uncertainty in scientific arguments?

Controversial Issues

Are there any controversial issues you cover in your science classrooms? What are these?

(Skip this question if there are no controversial issues) How do you use the argumentation practices when you cover the controversial issues?

Rural Setting

if in a rural setting How do you think being in a rural setting impacts your ability to integrate scientific argumentation practices into your classroom?

Are there any benefits? If so, what are they?

Are there any challenges? If so, what are they?

Ending

Is there anything you like to add?

Thank you for your help with my study. You will receive a gift card for participating.

BIOGRAPHY OF THE AUTHOR

Erin Doran spent time growing up in Camden, Maine, graduating from Camden Hillis Regional High School in 2016. She then attended the University of Maine, where she earned a Bachelor of Science in Biology (2019) and a Bachelor of Science in Secondary Education (2018). Erin spent her childhood jumping from one animal to another, starting with hamsters and ending with elephants. During these experiences she found her love of education working through various internships that educated people about land conservation, animal physiology and environmental sciences. In 2018, Erin enrolled in the Master of Science in teacher program at the University of Maine. She will be starting her first full time teaching job in Southern, Maine, teaching middle school science in the Fall of 2020. She is a candidate for the Master of Science in Teaching degree from the University of Maine in August 2020.