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Middle and High School Teachers' Perceptions of Data Literacy Concepts

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MIDDLE AND HIGH SCHOOL TEACHERS' PERCEPTIONS
OF DATA LITERACY CONCEPTS

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Data literacy is becoming an increasingly necessary skill, especially in the sciences. In recent years, more and more schools are including data literacy education in their K-12 curricula, particularly at the secondary level. To successfully implement such classroom projects, teachers must have the pedagogical content knowledge necessary to help students build their data literacy skills. Due to the interdisciplinary nature of data literacy, teachers are required to obtain knowledge outside their normal subject expertise. Data literacy focused interdisciplinary professional development can help teachers obtain the instructional skills necessary to help their students become data literate.

Before teacher educators can design effective data literacy professional development programs, they must understand what preconceptions teachers maintain about data literacy and related concepts. At the start of a research practice partnership between a University in the Northeast, a rural school district, and the surrounding community, seven teachers were interviewed about their perceptions of data literacy, authentic context, and quantitative reasoning. The teachers were predominantly high school science teachers, but included one middle school science teacher and one high school social studies teacher. Analysis of the interviews indicates

that teachers had robust conceptions of data literacy and authentic context, but not quantitative reasoning. Teacher descriptions of authentic context strongly informed their descriptions of data literacy, unlike quantitative reasoning which teachers described as a largely separate concept. When compared to academic definitions, the teacher descriptions taken together included almost all of the academic definition themes. As a whole, the results from this study lay the groundwork for future research in interdisciplinary data literacy professional development creation. Future research may also include a study of how teacher perceptions of the data literacy concepts change over the course of the research practice partnership.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AEP – Alternative Education Program

CK – Content Knowledge

DLFT – Data Literacy for Teachers

IRB – Institutional Review Board

NRC – National Research Council

NSF – National Science Foundation

PCK – Pedagogical Content Knowledge

PD – Professional Development

PK – Pedagogical Knowledge

RPP – Research Practice Partnership

STEM – Science Technology Engineering Math

TPACK – Technological Pedagogical and Content Knowledge

CHAPTER 1

INTRODUCTION

1.1 Data literacy pedagogical content knowledge

To say that we live in an increasingly data driven world is to paraphrase nearly every paper written about data literacy over the last several years (Finzer, 2013; Gould, 2020; Kjelvik & Schultheis, 2019; Miller, 2022; Schield, 2004; Wolff et al., 2019). A data literate public is now a societal necessity (Gould, 2017; Mayes et al., 2014). In recognition of the need for greater data literacy, researchers frequently call for data literacy to be taught in both K-12 and post-secondary education (Gibson & Mourad, 2018). Articles abound with data literacy lessons, units, and teaching techniques (Gould et al., 2014; Kastens et al., 2015). As helpful as these suggestions are, little research has been done on the pedagogical content knowledge (PCK) required to teach data literacy in the classroom (Miller, 2022).

The full extent of PCK required for teachers to integrate data literacy into their teaching strategy is far beyond the scope of this study. Instead, this study seeks to explore teacher preconceptions about data literacy and related topics. Teachers must be aware of student preconceptions and misconceptions that may hinder or aid student understanding of content (Ouch & Widiyatmoko, 2021). In the same way, teacher educators must be aware of teacher preconceptions, especially concerning a potentially unfamiliar topic such as data literacy. Preconceptions shape a teacher's understanding of and feelings toward data literacy, which, in turn, affects how they teach it. This study seeks to identify teacher perceptions regarding data literacy, authentic context, and quantitative reasoning. Doing so will help teacher educators gain a better understanding of how to help teachers achieve the PCK necessary to teach data literacy effectively.

1.2 Data literacy framework

Data literacy is relevant to every subject in school and, increasingly, many aspects of everyday life (Shield, 2004). It is not enough for a citizen to be literate in terms of reading and writing, people must now possess sophisticated literacy with regard to numbers (Carmi et al., 2020). Because it pervades so many academic subjects, a data literacy framework must be adaptable to a variety of contexts and disciplines.

This study uses the framework developed by Kjelvik and Schultheis (2019) in which they describe data literacy as the intersection of data science, quantitative reasoning, and authentic context (Figure 1). In this instance, data science refers to the ability to "perform computer science tasks including programing and developing digital tools to work with data" (Kjelvik & Schultheis, 2019, p. 2). Authentic context offers an environment in which students can develop their subject matter knowledge using real, scientific data (Kjelvik & Schultheis, 2019). Lastly, Kjelvik and Schultheis describe quantitative reasoning as the "[application of] theory to use and develop mathematical models, functions, and equations" (p. 2). Each of the three components overlap with each other individually to form distinct skill sets. Together the three concepts combine to form a concise definition of data literacy as the ability to "understand and evaluate information obtained from authentic data" (Kjelvik & Schultheis, 2019, p. 2).

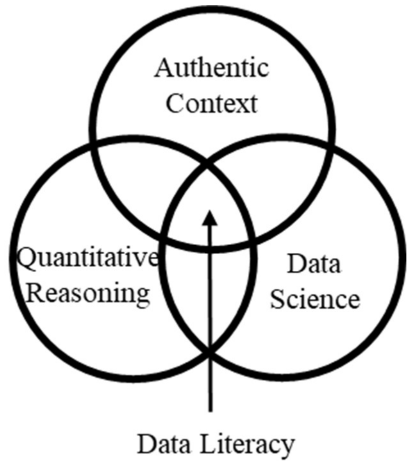

Figure 1: Data literacy as depicted by Kjelvik and Schultheis (2019). Data literacy exists within the overlap of data literacy, authentic context, quantitative reasoning, and data science.

1.3 Research context

This study took place within the context of a large research practice partnership (RPP) involving scientists and education researchers from a University in the Northeast, teachers and administrators from a rural, coastal school district, and business partners from the surrounding community (NSF Grant #2148520). The purpose of the RPP was to use community-relevant research projects to build students' science, technology, engineering, and math (STEM) skills while deepening their interest in pursuing STEM-related careers. The project also sought to strengthen connections between coastal school districts and their surrounding communities (McKay, 2022-2026).

Objectives for the RPP primarily focused on student gains in STEM skills, understanding of marine sciences, and awareness of STEM careers in the local area. To help achieve the student-oriented objectives, teachers participated in professional development (PD) summer institutes and ongoing cohort meetings to help them guide students through coastal research projects (McKay, 2022-2026). Teachers collaborated with education researchers to develop units and lesson plans designed to increase student engagement in authentic research within a marine science context. Before the first summer institute, teachers involved in the project participated in initial interviews concerning their background and teaching experience, descriptions of STEM-related concepts, and expectations for the project.

1.4 Research questions

This study used data taken from the interviews to determine teacher perceptions of data literacy and how their understanding of quantitative reasoning and authentic context informed those perceptions. Kjelvik and Schultheis (2019) offer a framework to define data literacy and its related concepts within the context of a K-12 classroom, but little research has been done on how teachers perceive these concepts. It is vital to understand how teachers think about data literacy concepts because teacher perceptions often affect how they present material in a classroom (Gow & Kember, 1993). Given the lack of research on teacher perceptions of data literacy, this research seeks to answer the following questions:

1. How do in-service middle and high school teachers describe the STEM-related concepts data literacy, authentic context, and quantitative reasoning?
2. How do in-service middle and high school teachers' descriptions of data literacy, authentic context, and quantitative reasoning compare to academic definitions in recent literature?
3. How do in-service middle and high school teachers' understanding of authentic context and quantitative reasoning inform their descriptions of data literacy?

To answer these questions, the author analyzed teacher interview transcripts using a deductive qualitative coding structure based on the framework established by Kjelvik and Schulteis (2019) and then expanded it using in vivo coding methods. The author seeks to determine teacher perceptions of data literacy concepts so that future PD can be tailored to accommodate and expand upon those perceptions.

CHAPTER 2

LITERATURE REVIEW

2.1 Pedagogical Content Knowledge

Shulman's (1986) framework defines Pedagogical Content Knowledge (PCK) as the overlap between teachers' knowledge of content and teachers' knowledge of how to teach effectively. Despite being closely related to both content knowledge (CK) and pedagogical knowledge (PK), PCK is its own entity that encompasses the knowledge of how to teach a particular subject. It includes topics such as the most difficult concepts within a discipline and the best ways to help students understand them. It also includes knowledge of frequent student preconceptions and misconceptions regarding a topic (Shulman, 1986). In essence, PCK is the knowledge necessary for teachers to enable student learning within a particular discipline.

Since Shulman (1986) introduced the concept of PCK, educational researchers have adapted and adjusted it to better explain what PCK includes. For example, Hashweh (2006) asserts that PCK represents private knowledge made up of the individual constructions teachers gain through planning, teaching, and reflecting on the experience. Some frameworks divide PCK into interrelated component parts (Magnusson et al., 1999; Park and Chen, 2012). Magnusson and colleagues (1999) focus on science education and suggest that PCK is comprised of a teacher's knowledge of science curricula, students' understanding of science, instructional strategies, and assessment strategies for science. All of this knowledge is influenced by the teacher's approach to teaching science (Magnusson et al., 1999). Others describe the most important characteristics of PCK, namely that PCK is dynamic and transforms different categories of knowledge so that they may be applied together, particularly content knowledge and the knowledge of how to teach (Abell, 2008).

Some researchers have expanded on Schulman's (1986) framework to accommodate other aspects of teachers' professional knowledge. Technological Pedagogical and Content Knowledge (TPACK), for example, includes not only CK and PK, but also teachers' knowledge of technology and how it can best be used in the classroom to improve students' understanding (Mishra & Koehler, 2006). Ball and colleagues (2008) expanded CK and PCK to include various subcategories of knowledge required of teachers, such as horizon content knowledge (understanding of content in the courses preceding and following the current class) and knowledge of content and students (understanding what students how students are likely to react to course material). The revised definitions and expanded frameworks are useful variations on the original theme for specific topics within different disciplines. Due to the interdisciplinary nature of the inquiry, this study will focus on the basic definition of PCK as teachers' knowledge of how to best present a topic so that students can gain an understanding of the material (Shulman, 1987).

2.1.1 Importance of teacher PCK

PCK is the knowledge base that sets teachers apart from other professionals (Shulman, 1987). It distinguishes a science instructor from a scientist. A teacher's PCK proficiency has a marked effect on student learning. Students tend to retain more information when teachers have a higher level of PCK. A study of high school math teachers and classes indicates that students of teachers with a higher level of PCK show significantly higher achievement after one year (Baumert et al., 2017). Another study found similar results in science classrooms (Förtsch et al., 2016). Teachers with higher levels of PCK created better learning opportunities for students, thereby enabling the students to perform better. CK is necessary for any teacher and an important prerequisite in developing teacher PCK, but it is PCK itself that empowers teachers to create high quality learning environments (Baumert et al., 2017; Förtsch et al., 2016).

2.1.2 Data literacy PCK

Professional development in cross-curriculum content areas such as data literacy is vital because without the appropriate support, teachers may not be comfortable with the material and, therefore, much less likely to implement new content (Guskey, 1988). To date, there has been limited research on the interdisciplinary PCK necessary for teachers to involve data literacy in their curricula (Miller, 2022). There are some programs, such as the *Maine Data Literacy Project*, that offer lesson plan suggestions along with teaching aids to help teachers incorporate data into their classrooms (Partners in Data Literacy, n.d.), but these programs do not delve into PCK requirements. According to Miller (2022), data literacy requires its own form of PCK, but she does not go so far as to delineate the PCK required to teach data literacy. Miller (2022) does suggest that the PCK for data literacy may be similar to the PCK related to integrated STEM education, including components such as teachers' attitudes towards data and teaching data, teachers' knowledge of students' understanding of data, and knowledge of strategies for teaching data literacy. Research indicates these components arise in teachers' classroom practices, particularly as they teach students to question data to determine its validity using examples relevant to student's daily lives (Miller, 2022). However, because it is a relatively new subject for K-12 education, more research is needed to further validate theories concerning the PCK teachers need to effectively introduce data literacy into their classrooms.

2.2 Data Literacy

Data literacy has become a much sought after skill in recent years (Baker, 2017; Wolff et al., 2016). As the world becomes more data dependent, society requires more individuals with the skills and knowledge to work with, analyze, and apply the findings of large data sets. Businesses require qualified workers who possess skills in a number of data literacy areas, from visualizing and communicating data findings to providing data driven insights regarding financial decisions (Wolff et al., 2016). The scientific community also needs data literate members. Scientists now have access to vast data sets, many of which they did not personally collect (Kastens et al., 2015). The community requires individuals who are well-versed in integrative scientific fields, such as chemistry, oceanography, and climate science, and have the computational abilities and data literacy necessary to analyze large data sets and communicate results (Elwood et al., 2019; Gibson & Mourad., 2018). Even biology, a subject typically thought of as less math-driven, has seen a surge of data without a corresponding increase in biologists capable of managing large data sets (Baker, 2017). Without enough data literate students who will become data literate scientists, some of the potential inherent within these large data sets will remain untapped.

The need for data literate individuals in STEM and business is well documented, but this need extends beyond professionals. With the staggering amount of easily available data, democracies require data literate citizens who are able to intelligently consume the data put before them and act accordingly (Gould, 2017). According to the National Research Council (2001), the global community is currently facing many environmental challenges, such as climate variability, hydrologic forecasting, and land-use dynamics, that can only be solved by collecting and analyzing large amounts of potentially complex data. To address these scientific challenges in the best manner possible, laypersons of the general populace must be able to understand and interpret scientific data to determine the best course of action (Mays et al., 2014). These grand challenges are not solely environmental issues. They exist at the intersection of scientific questions, politics, and social issues. The manner in which they are addressed will have a lasting effect on generations to come (National Research Council [NRC], 2001).

Citizens not only need to make informed scientific decisions, they must also be able to determine the quality of information they are receiving. Digital media is awash in disinformation, misinformation, and mal-information. Informed, data literate citizens have the skills to interpret such information and respond to it in a meaningful, appropriate way (Carmi et al., 2020). Without such abilities, individuals fall prey to disinformation and misinformation, from the unsupported link between vaccines and autism to allegations of election fraud (Hviid et al, 2019; McKelvy, 2020). Throughout the war in Ukraine, both sides have weaponized disinformation to their advantage. The damage caused by war-time disinformation extends beyond the borders of the conflict to influence global policy (Robinson et al., 2023). A significant amount of the misinformation and disinformation available through digital media concerns scientific topics, in particular climate change (Cook et al., 2018; Lewandowsky et al., 2013). Teaching students to be more data literate within a STEM context can help combat learner misconceptions about climate change while preparing them to be discerning citizens when consuming mass media (Cook et al, 2014).

2.2.1 Defining data literacy

Despite the ubiquitous need for data literacy in science and society, a single definition of data literacy is difficult to determine. Even though data literacy is interdisciplinary by nature, most definitions depend on context and are specific to a particular vocation or field of study (Wolff, 2016). For example, Gould (2017) and Schield (2004), both statisticians, emphasize the importance of statistical literacy within data literacy. Their definitions of a data literate person extend to someone who consumes information critically and understands how data is collected, processed, owned, and used in modern society. Others, such as research librarians, define data literacy in terms of the ability to navigate the storage and organization of the enormous data sets available to researchers today (Carlson et al., 2011). Researchers concerned with the deluge of questionable information available on the internet define a data literate person as one who can recognize disinformation, misinformation, and mal-information and act appropriately (Carmi et al., 2020). A data literate scientist is typically defined as one who can organize, analyze, integrate, and share the findings of a large data set (Baker, 2017; Gibson & Mourad, 2018).

With regard to education and educators, data literacy is generally defined in one of two ways. The first definition of data literacy concerns teacher data literacy and the ability to use data gathered from the classroom to make informed, practical decisions (Mandinach & Gummer, 2016). This definition, called Data Literacy for Teachers (DLFT), focuses on the skills teachers need to collect student data, analyze it, and use it to inform their teaching practices. DLFT is sometimes confused with assessment literacy, or the ability to make instructional decisions based on student assessment scores. Although assessment literacy is an important aspect of DLFT and assessment results are some of the most tangible data available to teachers, DLFT seeks to look beyond assessments and include all sources of data available to teachers (Mandinach & Gummer, 2016). To be data literate, teachers must incorporate their knowledge of content, curriculum, students as individuals, contexts, and pedagogical knowledge (PK). The PK described by Mandinach and Gummer (2016) includes both general PK and PCK as described by Shulman (1986). However, the PCK referred to in this area of research is the knowledge necessary to teach students a subject within the teacher's discipline, chemistry for example, not the PCK required to teach students to be data literate. DLFT is concerned solely with teachers' ability to use data themselves, not their ability to build student data literacy skills.

The second group of data literacy definitions within education concerns what constitutes a data literate student. Some definitions focus on the abilities needed by a data literate secondary or postsecondary student, particularly a student in a science related field. These definitions include skills such as selecting the correct analytical tool, applying the tool in context as part of an experiment, analyzing and interpreting data with regard to a question or hypothesis, and communicating the findings in an effective manner (Gibson & Mourad, 2018). Other definitions take a broader context to include students who will grow into data literate citizens or join non-scientific professions that require data handling knowledge. These definitions include similar skills to those described for a data literate science student, but also include additional attributes such as understanding and abiding by the ethics of gathering and using data (Carmi et al., 2020, Schield 2004). Some definitions also include a reference to specialist skills depending on the context in which data is used (Wolff, 2016).

This paper focuses on the definition of data literacy set forth by Kjelvik and Schultheis (2019), namely that data literacy exists in the overlap among data science, quantitative reasoning, and authentic context. This definition is broad enough to capture a wide range of context dependent definitions. Placing data science within a data literacy framework captures the data management aspects put forth by Gould (2017) and Carlson and colleagues (2011). Quantitative reasoning includes the mathematical processing, analyzing, and communicating skills called for by Schield (2004). Lastly, authentic context provides the real-world application necessary for data literacy to become the useful scientific tool described by Gibson & Mourad (2018), not just an academic exercise. Kjelvik and Schultheis' definition may be applied to both teachers and students; DLFT fits squarely within it, as do the skills necessary to a data literate student.

2.2.2 Data literacy and interdisciplinary Professional Development

Data literacy touches so many aspects of every subject, it is by its very nature interdisciplinary. It combines a variety of knowledge and skills from differing disciplines, including mathematics, science, computer science, and communication (Elwood et al, 2019; Gibson & Mourad, 2018). The interdisciplinary nature of data literacy makes developing pre-service teacher training and in-service teacher professional development (PD) a challenge (Miller, 2022). Programs such as these usually focus on only one discipline. A teacher may undergo training in mathematics or science education, but not usually both. To teach an interdisciplinary subject such as data literacy effectively, a teacher will need expertise outside their chosen discipline, including PCK beyond the subject they normally teach (NRC, 2014).

To create and implement effective interdisciplinary PD, researchers must have an interest in education beyond their academic field (Miller, 2022). Teachers must be willing to expand beyond the boundaries of their subject (NRC, 2014). School districts must also be willing to implement an interdisciplinary curriculum. To do so, districts must allow teachers from different departments the time and support needed to build cross-curricular data literacy units that meet local state and district mandated standards (NRC, 2014; Vahey et al, 2012).

With so many factors to account for, developing a PCK requirement for data literacy is an ongoing challenge (Miller, 2022). Different teachers will have different PCK and PD requirements, depending on their subject and background (NRC, 2014). Pre-service training affects how a teacher approaches data literacy. Math teachers will see data literacy through a mathematics lens; science teachers will see it from a science perspective (Finzer et al, 2018; Moore, 2014). To overcome this challenge, researchers must continue to seek ways of providing interdisciplinary PD to teachers with a variety of perspectives and backgrounds (Miller, 2022; NRC, 2014).

2.2.3 Current research in data literacy education

Like the data literacy definitions associated with education, research into data literacy education tends to fall into one of two categories: DLFT and teaching data literacy to students. Researchers devoted several studies to developing a framework to define DLFT based on the need for greater data informed practices among educators (Gummer & Mandinach, 2015; Mandinach & Gummer, 2016). Researchers have also defined a continuum of levels of expertise regarding DLFT ranging from novice to expert in five actions based on Mandinach and Gummer's (2016) conceptual framework (Beck & Nunnally, 2021). The purpose of the framework and continuum is to develop programs to help teachers make better use of data within their classrooms. To that end, researchers have called for increased data literacy education both in pre-service teacher training programs and during in-service teacher professional development (Beck & Nunnally, 2021; Mandinach & Gummer, 2016). As stated above, though, this research only concerns teachers' ability to use data as a support within their classrooms, not their ability to teach data literacy to students.

Research into teaching data literacy tends to concern the development of units and lesson plans aimed at helping teachers raise data literacy. Wolff and colleagues (2019) offer several lessons they developed alongside teachers to help students build data literacy by using publicly available data to answer real-world questions. Another data literacy unit integrates publicly available data with mapping software to create a project-based learning unit (Finzer et al., 2019). As is the case with most data literacy products, both units are intended for a science classroom. Only a small amount data literacy education research takes an integrated, interdisciplinary approach (Miller, 2022). Unlike STEM education, which has developed frameworks for integrating STEM subjects within each other and with other school subjects (Dare et al., 2021; Kelley & Knowles, 2016), data literacy education research is largely limited to science and statistics classrooms. Vahey and colleagues (2012) provide an exception. They developed a cross-disciplinary data literacy unit for middle school involving science, math, English, and social studies. Despite identifying several difficulties in executing a unit involving several classes across eight weeks, they found that such an integrated curriculum design was not only possible, it resulted in an increase in student data literacy and a higher performance in subject matter content (Vahey et al., 2012). In addition to a lack of research into cross-disciplinary data literacy, there is also a lack of research on the PCK necessary for teachers to develop student data literacy effectively. Some of the data literacy lesson plans suggest instructional strategies, but there is little research examining what teachers already know about data literacy and how they effectively implement that knowledge in the classroom (Miller, 2022).

2.2.4 Data science within data literacy

Data science is a recognized component of data literacy (Kjelvik & Schultheis, 2019). Often, data science is defined as an even combination of computer science, mathematics and statistics, and specialty expertise, such as psychology or sports analysis (Conway, 2010, as cited in Smith, 2010). Other data science education researchers contend that data science contains far more statistics than computer science or traditional, abstract mathematics. Despite reiterating the importance of computer science and mathematics within data science, these researchers contend that statistics are the core of data science around which everything else revolves (Baumer, 2015; Gould, 2020). Data science skills encompass several data literacy areas of expertise, including the ability to acquire data and communicate findings (Baumer, 2015). However, data science also concerns computer science skills not usually associated with data literacy, such as setting up a data server or automating the merger of multiple data sets (Baumer, 2015; Finzer, 2013).

Some of the teachers offered descriptions of data literacy that included data science topics even though they were not asked about data science specifically. For the purposes of this study, data science is defined as the intersection of computer science, mathematics, and statistics. Teacher descriptions are labeled as data science if they include data science topics that are exclusive of data literacy.

2.3 Authentic context

Authentic context occurs any time real-life experiences are brought into the classroom. In science classes, this means involving students in data sets from actual scientific research (Kjelvic & Schultheis, 2019). K-12 science classes often use curated data sets to illustrate a specific point. Although these textbook data sets can be helpful in some regard, Kerlin et al. (2009) and Wolff et al., (2019) observed that student scientific understanding improves when they are exposed to messy data in a real-world context.

Students may obtain data through a number of sources including collecting their own data, relying on secondary sources such as publicly available databases, or a combination of the two (Kastens et al., 2015; Kjelvic & Schultheis, 2019). To collect their own data, Students may use measurements, observations, or remote sensors (Kjelvic & Schulteis, 2019). When students collect their own data (primary data), they tend to have a higher level of emotional involvement in the project. Students report being excited about learning new skills and participating in activities similar to those they associate with professional scientists (Gould et al., 2014). Unfortunately, student-gathered data sets tend to be smaller and less complex than the data sets scientists now routinely use (Kastens et al., 2015). In order to become data literate, students must be exposed to the large, secondary data sets used throughout science today (Gibson & Mourad, 2018). To combine the best of both worlds, students can interact with large data sets to which they are able to contribute. For example, a class studying the water quality of a nearby river may combine their data with the data from other schools located along the river (Kastens et al., 2015). Technology has also opened opportunities for students to contribute to large data sets. Gould (2017) refers to this as "participatory sensing" (p. 23) because every individual who contributes to the data has access to the data. In Gould's 2017 example, students across Los Angeles submitted data every time they discarded an item, including the category (recyclable, compostable, landfill), where it was discarded, what discard options were available at the time, a description of the item, and a picture. The data was available to students real time as it was collected. While there are advantages and disadvantages to primary and secondary data, both contribute to increased student data literacy. With the prevalence of data in today's society, every science classroom has the potential to involve authentic data (Gould, 2017; Wolff, 2019).

2.3.1 Advantages of authentic context

The advantages of using authentic context in science classrooms are numerous and well documented (Gould et al., 2014; Kastens, 2015; Kerlin et al., 2015). Not only does authentic context increase students' STEM related skills, it increases students' positive emotions towards STEM. Authentic context enables students to engage in scientific exploration with non-curated data and no "right" answers (Gould et al., 2014). In one example, students requested that automated telescopes capture images of a star at specific times during the night. Students then use the data to identify planets orbiting the star (Gould et al., 2014). Authentic context also improves students' critical thinking and scientific arguments (Holmes et al., 2015). In a study conducted during a calculus-based physics lab, Holmes and colleagues (2015) found that authentic data combined with scaffolded instruction on quantitative comparison of data sets and experiment design significantly improved students' abilities to analyze data. Similarly, Kerlin and colleagues' (2015) study of high school students' scientific arguments found that, when presented with authentic data, students engaged more complex arguments using a wider range of techniques to substantiate their claims. Overall, authentic context improves student data literacy by giving them the skills to collect data and organize data, analyze it, and draw scientific conclusions (Kastens, 2015).

As well as improving students' data analysis and argumentation skills, authentic context garners more student interest. Engaging with authentic data increases students' sense of their own science identity (Esparza et al., 2020). Students involved with authentic data also report greater motivation to continue their STEM education and pursue a STEM-related career (Corwin et al., 2018; Esparza et al., 2020). With increased motivation often comes an increase in student confidence and self-efficacy within science (Szteinberg & Weaver, 2013). Authentic context also elicits a greater emotional response from students: they care about the results because they want to know the answer (Gould et al., 2014). With authentic context, students feel that they are participating in "real" science (Langen et al., 2014).

2.3.2 Authentic context integration in classrooms

Although teachers sometimes spontaneously introduce authentic context to science classrooms at the beginning of a unit or to explain a concept, most instances of authentic context take place as part of preplanned lessons or units (Davidsson & Granklint-Enochson, 2021). Authentic context may be folded into an entire unit, as demonstrated by Gould and colleagues' (2014) example of students searching for planets in distant solar systems. Alternately, authentic context may be introduced in individual lessons through short activities such as data puzzles, in which students receive small sets of authentic data to answer questions (Kastens et al., 2015). On a larger scale, authentic context can be integrated across curricula, drawing connections from social studies to science to math to English (Vahey et al., 2012). Whether introduced within a single lesson, as part of a unit, or as an integrated program, authentic context improved students' data literacy skills (Gould et al., 2014; Kastens et al., 2015; Vahey et al., 2012). Despite a number of articles with pre-built units, lessons, and suggestions on how to incorporate authentic context into classrooms, there is little research on teacher perceptions of what constitutes authentic context.

2.4 Quantitative reasoning

Quantitative reasoning appears in many settings and goes by several different names including quantitative literacy, numeracy, number sense, and contextualized mathematics (Mayes et al., 2014). Though there may be subtle differences in the definitions of these terms depending on the context (Varcher, 2014), the author treated them as synonyms and used quantitative reasoning as an umbrella term.

Definitions of quantitative reasoning vary depending on the context and emphasis desired (Boersma & Klyve, 2013). A review of the most common definitions elicits a number of common themes. First and foremost, quantitative reasoning deals with real-life issues and contexts (Steen, 2001), unlike pure mathematics which includes an abstract aspect that quantitative reasoning does not (Mayes et al., 2013). Quantitative reasoning is rooted in everyday experiences, both personal and professional (Grawe, 2011). Secondly, quantitative reasoning largely involves basic mathematical and statistical skills, not advanced mathematical concepts (Wilkins, 2000). The difficulty in quantitative reasoning is not the math itself, it is the sophisticated way in which basic mathematical principles must be applied to solve messy, realistic problems (Grawe, 2011). Quantitative reasoning is required to solve those problems for which a memorized mathematical algorithm will not work (Boersma & Klyve, 2013). Opinions vary on the mathematical skills required by quantitative reasoning, but they generally include arithmetic, measurement, percentages, the ability to interpret graphs, a basic understanding of probability and statistics, and knowledge of growth patterns (Hallett, 2008, as cited in Grawe, 2011). Most definitions of quantitative reasoning also include an aspect of interpreting and analyzing data to form a logical conclusion. In many respects, this is simply the ability to make sense of numerical data through critical thinking (Wilkins, 2000). Lastly, several definitions of quantitative reasoning encompass communication. It is not enough to draw conclusions and make decisions based on data, an individual must be able to communicate their findings or intentions to another (Mayes et al., 2014; Steen, 2001).

The author uses the definition of quantitative reasoning put forth by Mayes and colleagues (2014):

> Quantitative reasoning is mathematics and statistics applied in real-life, authentic situations that impact an individual's life as a constructive, concerned, and reflective citizen. Quantitative reasoning problems are context dependent, interdisciplinary, open-ended tasks that require critical thinking and the capacity to communicate a course of action. (p. 637)

This definition encompasses the previously described themes while emphasizing the real-world context of quantitative reasoning. The above definition is robust enough for the purposes of this study, but it lacks one aspect of quantitative reasoning present in much of the literature: a habit of mind (Boersma & Klyve, 2013; Grawe, 2011). Many researchers consider quantitative reasoning as a way of thinking, rather than a skill set. People with quantitative reasoning skills see the world around them through a mathematical lens (Steen, 2001). They tend to seek out quantitative information when analyzing situations and making decisions (Boersma & Klyve, 2013).

Although this is an important aspect of quantitative reasoning, this study focuses more on the skills required to improve quantitative reasoning as opposed to the habits maintained by people who possess strong quantitative reasoning abilities.

2.4.1 Quantitative reasoning in classrooms

Quantitative reasoning is an essential aspect of data literacy. It is integral to every discipline of science and a skill required of informed citizens (Marder, 2017; Mayes et al., 2014). Scientists are seeking ways to increase student quantitative reasoning abilities (Aikens & Dolan, 2014). As the scientific disciplines become more integrated, scientists with mathematical and quantitative reasoning skills will be in greater demand (Marder, 2017). With the rise in large data sets, students must have a set of quantitative reasoning skills if they are to be successful in STEM fields.

At present, quantitative reasoning education is most closely associated with mathematics classes, but there is a significant movement to integrate quantitative reasoning across different disciplines, particularly in science (Keenhold, 2019; Piatek-Jimenez et al., 2012). Some research suggests showing students a photograph or short video and using "What do you notice?" prompts to help students develop their quantitative reasoning skills through observation (Weber et al., 2012). Piatek-Jiminez and colleagues (2012) suggest assigning realistic problems that cannot be solved using a specific method or algorithm. Solutions to issues such as choosing a cell phone plan or deciding whether or not to trade in a car are rarely simple and vary depending on the student. A math class might be the most obvious place to implement questions of this nature, but they could be adapted for any subject (Piatek-Jimenez et al., 2012). Keenhold (2019) describes an assignment type developed by the *Maine Data Literacy Project* in which students were given a data set and asked to create a story around it. Students framed questions that could be answered by the data set, then analyzed and interpreted the data to support their answer. Additionally, students created graphs and practiced communicating their findings (Keenhold, 2019). Data story assignments such as these may be implemented in any classroom and lend themselves particularly well to science.

2.4.2 Teacher quantitative reasoning

Unlike data literacy, many teacher education programs include some training in teaching quantitative reasoning, both for pre-service and in-service teachers. However, this training is primarily focused toward mathematics teachers (Moore et al., 2014; Stump, 2017). Few, if any, teacher preparation programs include dedicated quantitative reasoning for science or humanities educators. Some mathematics professional development courses require teachers to prepare quantitative reasoning tasks for use in mathematics classrooms. By creating and refining quantitative reasoning activities, teachers improve their own quantitative reasoning skills and their ability to teach qualitative reasoning within their classrooms (Glassmeyer, 2019; Stump, 2017). Others present pre-service teachers with mathematical problems that challenge their understanding of the "rules" of mathematics. By working through each question, pre-service teachers build their quantitative reasoning skills and understand how to better address some student misunderstandings in mathematics (Moore et al., 2014). These methods of improving educators' ability to teach data literacy appear to be effective, but classes such as those described above are generally only required for future mathematics teachers. Such methods of teaching data literacy could be just as relevant to a science or humanities teacher.

Teacher quantitative reasoning skills are also necessary for Mandinach & Gummer's (2016) DLFT framework. In order for teachers to use student data to inform their classroom practices effectively, they must have the quantitative reasoning skills necessary to make sense of the data at their disposal. Cowie and Cooper (2017) found that pre-service teachers often lack the necessary quantitative reasoning and statistical interpretation abilities required to deal with student data. Many of the teachers acknowledged that such skills were an important aspect of the teaching profession, but they lacked confidence in their own mathematical and quantitative reasoning skills. Despite their lack of confidence, many teachers expressed a desire to improve their quantitative reasoning skills so that they could make better use of student data within their classrooms (Cowie & Cooper, 2017).

CHAPTER 3

METHODS

3.1 Study context and participants

This study occurred within the confines of a four-year research practice partnership (RPP) involving a University in the Northeast, a small coastal school district, and members of the surrounding community. Study participants were members of the first of two cohorts of teachers involved with the project. Ten teachers self-selected to take part in the project and seven teachers volunteered to make themselves available for interviews over the summer (Table 1). Institutional Review Board (IRB) approval was obtained prior to the first interview. Six participants were high school teachers, and one was a middle school teacher. All but one of the teachers were involved in some aspect of STEM education. The only teacher who did not teach a traditional STEM subject was a high school social studies teacher. One of the high school teachers was involved in an alternative education program (AEP) and so taught other subjects as well as STEM topics.

Grade Band	Teacher Pseudonyms (Discipline [years of experience])
High School	John (Social Studies [31]) Roger (Physics, Marine Science, Fish & Wildlife [23]) Kitty (Chemistry, Physics, Marine Science [7]) Peggy (Technology Coordinator [50]) Jim (Engineering, Computer Programing [20])
High School AEP	Susan (Physical/Life Science, Math, Writing [5])
Middle School	Nancy (Physical/Earth Science [11])

Table 1: Study participants. Teachers in the study included high school, middle school, and AEP teachers with a variety of subject specialties and varying amounts of teaching experience.

3.2 Data collection and analysis

Interviews were conducted via video conferencing before the cohort's first professional development workshop. The same university staff member conducted all the interviews using the script and semi-structured format contained in Appendix A. The interviewer asked every question on the script along with follow-up questions as required. Teachers were sent the interview protocol via email when the interview was scheduled so they could read over the questions and gather their thoughts if they chose. Questions were designed to elicit teachers' perceptions and descriptions of data literacy, authentic context, and quantitative reasoning. The interview protocol included one question each about authentic context and quantitative reasoning. Two questions were dedicated to data literacy. The first asked the teachers about "working with data" while the second asked for their perceptions of data literacy specifically.

Before coding, all interviews were transcribed verbatim. The coding process involved a mix of deductive and inductive coding. The qualitative analysis for this study adopted several tenets of the grounded theory framework even though there was no intention of creating an original theory. Procedures adopted from grounded theory included analyzing concepts drawn directly from teacher interviews and combining concepts into groups of concepts pertaining to related ideas (Corbin & Strauss, 1990). Additionally, a form of memo/code note-writing was used to formulate and revise the codebook and data analysis. Initial qualitative coding used the deductive "template analytic technique" described by Miller and Crabtree (1992) in which a researcher develops codes based on an established framework. In this case, question responses were coded as data literacy, authentic context, data science, and quantitative reasoning based on the Kjelvik and Schultheis (2019) framework. All responses were coded according to the question asked, regardless of the content of the excerpt. For example, a response to a question about data literacy was coded first as data literacy even if it contained aspects more closely related to quantitative reasoning. Since the teachers were not explicitly asked about data science, the data science code was applied in addition to the other three codes, regardless of the question asked. After the interviews were coded using the three initial parent codes, data driven codes were developed using an iterative process similar to the one described by Boyatzis (1998). This inductive coding began with three interviews: a high school science teacher, the AEP teacher, and the social studies teacher. These interviews encompassed a variety of perspectives, thereby establishing a wide breadth of codes.

The first iterations of inductive coding utilized in vivo coding (Saldaña 2016) to develop a codebook based on the three selected interviews. Later iterations moved toward a focused coding approach in which in vivo codes were categorized and combined (Saldaña, 2016). As an example, references to students performing data collection outside the realm of a “cookbook lab” and references to students erroneously searching for a “right answer” were combined and coded as “unknown nature of science”. “Lack of ‘correct’ answers’” and “Science as a process, not a list of instructions” were retained as child subcodes under “unknown nature of science”. After several iterations of both in vivo and focused coding, the remaining four interviews were coded using Dedoose qualitative analysis software. After consultation with another member of the RPP team, the codebook was further refined and the final codebook was used to code all seven interviews (Appendix B). Figure 2 displays an example excerpt coded from the final codebook.

> “It means just engaging them in things that are meaningful to them, either because they’re interested* or because it’s in their community†, or because it’s something that impacts their day to day lives‡.” (Susan)
>
> Parent code: Authentic context
>   Child code: Meaningful to students
>   Child subcodes: Student interest*
>   Place-based†
>   Relates to students’ daily experience‡

Figure 2 Example of coding. In the excerpt depicted, the parent code is “Authentic context” because the excerpt was given in response to a question about authentic context. The child code is “Meaningful to students” because the entire sentence is about making the subject matter meaningful to the class. The child subcodes describe why the material might be meaningful to a student.

Research question one sought to understand how teachers describe data literacy and related topics and so required that the major themes present in each concept be recognized. To determine the most prominent codes related to each concept, the author primarily considered the number of times the code occurred and the number of teachers received the code on at least one excerpt. The author also considered the distribution amongst the teachers. For example, two codes were used six times on three teachers. In one instance the code was used four times for one teacher and in the other, the code was used twice for each teacher. The even distribution would be considered the more prominent code within the group. In cases where a prominent code was a child subcode, it was folded into the child code for the purposes of analysis.

After the final codebook was established and each interview was coded, the results were analyzed for instances of code co-occurrence and grouping. An instance of code co-occurrence was defined as when two or more teachers have the same codes applied while discussing the same topic. For example, if four teachers all receive codes for both "extracting meaning from data" and "using data for real-world applications" on responses concerning data literacy, it would be considered and instance of code co-occurrence. Grouping was defined as two or more teachers who received the same code and had another attribute in common. An example of grouping occurred when the three traditional science classroom teachers all received the code for "the unknown nature of science" when discussing authentic context.

When comparing teacher descriptions to academic definition in an effort to answer research question two, major themes in academic definitions were determined using an analysis of recent literature similar to the "Themeing the Data" (p. 198) technique defined by Saldaña (2016). The interviews were analyzed for instances in which teachers discussed a topic related to the academic definition theme. Teacher quotes that best matched the academic definition were selected. In cases where the academic theme covered a range of topics, such as the mathematical skills required for quantitative reasoning, the teacher quotes typically only touched on one or two of the topics. The teacher quotes selected matched the greatest number of topics within the academic definitions.

To explore how teacher descriptions of data literacy and authentic context related to their perceptions of data literacy in answer to research question three, the author compared the codes that emerged from teachers' discussions of authentic context and quantitative reasoning to those from data literacy. The more child codes and child subcodes two topics had in common, the greater the overlap between the two. For example, authentic context and data literacy had a several similar codes in common and, therefore, a significant amount of overlap.

CHAPTER 4

RESULTS

The coding process elicited several codes under the three topics discussed: data literacy, authentic context, and quantitative reasoning. Of the codes that emerged, three codes per topic arose as the most predominant. The codes for each topic give a broad indication of how teachers think about data literacy, authentic context, and quantitative reasoning as individual concepts and serve to answer research question one.

After the predominant codes were determined, they were compared to themes in academic definitions taken from recent literature. For each topic, a table shows a quote from one of the interviews typical of one representing the academic definition theme in question. Unsurprisingly, none of the teacher's individual responses matched every aspect of the academic definitions. The definitions were gathered from a variety of sources working in several fields. When taken as a whole, though, the teacher descriptions touched on all but three of the academic definition themes, including those themes outside the realm of a typical science classroom.

Lastly, the codes generated from teacher descriptions of authentic context and quantitative reasoning were compared the codes elicited from their descriptions of data literacy in order to judge the amount of overlap among the three topics. Comparisons of the codes indicate a strong overlap between teachers' perceptions of authentic context and data literacy, but far less overlap between their perceptions of quantitative reasoning and data literacy.

4.1 Teacher perceptions of data literacy concepts

Teachers were asked to give their descriptions of each of the following concepts: data literacy, authentic context, and quantitative reasoning. Many of them discussed the concepts in terms of student skills or desired student outcomes. Teachers talked about student skills regardless of whether the question mentioned students or only asked about teacher perception. For example, “What does engaging students in authentic research mean to you?” often elicited the same student-centered response as “What does reasoning quantitatively mean to you?” Since all but one of the educators teach in at least one science discipline, most answers are rooted in the science classroom. In the following three excepts, Kitty, Peggy, and Nancy all gave answers about data literacy in terms of desired student outcomes in a science classroom after being asked what applying data literacy means to them.

> “Applying data literacy means that students should be able to look at a set of data and have some sense of what that means and how to get to meaning, you know, through graphical representation, or something like that.” (Kitty)

> “That’s where [students] can take the information and graph it in different ways to show different things. And communicate that to – be able to actually communicate that data to different organizations or people that are going to use that data to make decisions.” (Peggy)

> “And that’s really the hardest part, trying to interpret, ‘Okay, so now I have this picture. What does it mean?’ And that is really important for kids to have those opportunities to really try and look at a graph and make some sense of it.” (Nancy)

Several codes emerged, based on the teachers’ responses. Within each topic, three codes stood out as more prominent than the rest, both because of the number of teachers to whom the code was applied and total number of excerpts with the code. Table 2 (on next page) displays all the codes for each concept along with how many teachers had the code applied to a response and the total number of excerpts with the code.

Concept	Predominant Codes (number of teachers to whom the code was applied, total number of excerpts with code) Other Codes
Data Literacy	• **Data interpretation and analysis (6, 31)** • **Using data for real-world applications (5, 7)** • **Collecting data (4, 8)** • Applying computer science skills (3, 5) • Managing data (2, 4) • Using data to inform teaching practices (2, 3) • Applying mathematical principles (2, 2) • Teacher difficulty (1, 4) • Identifying the purpose of data (1, 3) • Communicating information via data (1, 2) • Teacher requestions clarification (1, 1)
Authentic Context	• **Students conducting authentic research (7, 21)** • **Meaningful to student (3, 10)** • **Unknown nature of science (3, 7)** • Incorporating a larger project (2, 2) • Project based learning (2, 2) • Learning extends to other areas (1, 2) • Maintaining teacher enthusiasm/interest (1, 2) • Students learning about authentic research (1, 1)
Quantitative Reasoning	• **Quantitative interpretation and analysis of data (3, 10)** • **Real-world applications (3, 5)** • **Teacher lack of knowledge (2, 3)** • Using mathematical reasoning for problem solving (1, 2) • Making data relevant to the lay person (1, 1) • Using current data to inform future research (1, 1) • Working with statistics (1, 1)

Table 2: Codes derived from teacher responses. Teacher responses included several codes under each of the three concepts: data literacy, authentic context, and quantitative reasoning. For each concept, the three codes that occurred most frequently are in bold.

4.2 Data literacy

Of the three concepts discussed during interviews, teachers provided the most robust, detailed responses to questions concerning data literacy. Responses indicate that the teachers were aware of the importance of being able to work with and glean information from large data sets. Academic definitions elicited nine themes, eight of which were present in at least one of the teacher responses.

4.2.1 Data literacy description predominant codes

Teacher descriptions of data literacy revolved around students doing hands-on work with real data, usually data the students had collected themselves. The predominant codes spanned the entire process of working with data starting with data collection and moving through data interpretation and analysis and using data for real-world applications.

4.2.1.1 Collecting data

Over the course of the interviews, four teachers mentioned the skills required to collect data while discussing data literacy. Teachers felt that students were more than able to take the lead in data collection. John asserted, “I think the data collection is key. How you do it, who does it. I think students are totally capable of being assigned pretty important roles. I think they like that. I think some thrive under that.” Teachers acknowledged that data can come from secondary sources, but nevertheless felt having the students collect their own data was an integral part of data literacy.

4.2.1.2 Data interpretation and analysis

Teachers most commonly discussed data literacy in terms of students’ ability to interpret and analyze data. Topics within interpretation and analysis ranged from creating a visual representation of data or interpreting a graph to garnering meaning from data and drawing conclusions. Four of the teachers mentioned graphing in conjunction with data literacy, specifically helping students determine the best way to visualize their data and then use the visualization to answer questions. Roger described helping students determine "how to represent relationships via the type of graph you might use. Is it a bar graph, line graph, scatter plot, you know?" After students had created a graph, teachers were equally concerned with how students interpret the information depicted. Nancy referred to the difficulty her middle school students have when reading a graph saying, "That's really the hardest part, trying to interpret, 'Okay, so now I have this picture. What does it mean?'"

Outside of graphing, teachers tended to focus on two aspects. First, they felt students should know how to extract information from the data. Kitty, for example, stated, "Applying data literacy means that students should be able to look at a set of data and have a sense of what that means and/or know how to get meaning." Second, teachers often discussed relating that meaning back to the original context, whether it be an in-class experiment or ramifications for real-world issues. Nancy described finding that context as the culmination of the exercise saying,

> "Once you have the data, you've made the visualization, that final piece of trying to connect it back to what does it mean? I feel like that's the application. Because now you're trying to connect it back to whatever the subject is."

In teachers' minds, data interpretation and analysis begins with finding a way to organize and make sense of data and continues all the way to drawing a meaningful conclusion about the results.

Curiously, only one teacher mentioned communicating information to others using data, despite it being a key tenet of science practice. In fact, the teacher who did mention it was Peggy, a technology specialist, not one of the traditional science classroom teachers. The science teachers tended to focus on students being able to create a visual, but not necessarily with the aim of presenting that data to other people. They also focused on students gaining a deeper understanding of data with which they were presented, but did not address students passing their understanding on to people outside the classroom.

4.2.1.3 Using data for real-world applications

Four teachers related data literacy directly to real-world applications. Some did so hypothetically while others referred to specific projects in which student collected data was used by a wider audience. In a general sense, Kitty mentioned how data literacy might include "looking at what these changes in data mean over time, and going back from what these numbers mean … what the consequence in the real world is." Peggy discussed a project in which students collect data on sea level rise: "Those computers are accessing the data from the ocean and sending that data to the – I think it's the harbormaster's office. And then they're using that data to make decisions in the community." Whether they spoke about a specific experience or a general use for data, teachers agreed that data literacy involves some authentic context.

4.2.2 Code co-occurrence in data literacy

The one instance of code co-occurrence in data literacy centered around the idea of extracting meaning from data. Five of the seven teachers interviewed mentioned extracting meaning from data. The teachers who discussed extracting meaning from data came from a variety of backgrounds ranging from traditional science classroom teacher to technology coordinator. Of those five, four of them also talked about using data for real-world applications. Additionally, four of the teachers who mentioned extracting meaning from data also touched on interpreting graphs. To many of the teachers, data literacy is closely tied to creating and garnering meaning from a graphical depiction of data. Teacher responses concerning data literacy did not form any significant groupings.

4.2.3 Teacher descriptions of data literacy compared to academic definitions.

Despite focusing on analyzing and interpreting data, at least one teacher mentioned some aspect of the other major themes in the academic definitions. One teacher even mentioned students' ability to identify misinformation and disinformation, although this answer was given in response to a question about authentic context, not data literacy. Another teacher touched on Data Literacy for Teachers (DLFT) and using data to inform classroom practices. The only theme not mentioned by the teachers was the idea of ensuring data is handled ethically. This omission is understandable given that the academic definition was put forth by a statistician who was concerned with privacy and peoples' personal information. There are times when personally identifiable information is a factor in scientific research, but it is rarely an issue in a high school science classroom.

Table 3 lists all nine of the academic definition themes as well as one quote that exemplifies a teacher response relating to the academic theme. In some cases, like the ability to navigate the storage and organization of large data sets, the teacher quote matches the academic definition theme closely. In other examples, such as the academic definition concerning critical data consumers, the teacher quote only touches on one aspect of the academic definition. The total number of teachers who mentioned something relating to the academic definition theme indicates how strongly the teachers associate that theme with the concept of data literacy.

Data Literacy	
Academic Definition Theme	**Example Quote [# of teachers who mentioned the theme]**
Analyzing and interpreting data (Gibson & Mourad, 2018)	"Then, you know, extracting some sort of quantitative modeling of the data. So what can you conclude from the data? Making conclusions from the data, yeah." – Roger [6 of 7]
Selecting and applying the correct analytical tool (Gibson & Mourad, 2018)	"I think the visual, like trying different visual representations and having the kids kind of look and compare about what these things show… CODAP© is so neat because they can just quickly – here's one thing, and then if we move this, you can compare it in this direction." – Nancy [3 of 7]
Ability to navigate the storage and organization of large data sets (Carlson et al., 2011)	"I think teaching the students, and maybe the teachers too, how to accumulate the data, how to organize it… I'm always a big advocate of databases." – John [2 of 7]
Critical data consumer who understands how data is collected, processed, owned, and used (Gould, 2017)	"… making them aware that you can use statistics to change the way you can view data to understand it in different ways". – Kitty [2 of 7]
DLFT: Teachers using data to inform classroom practices (Mandinach & Gummer, 2016)	"Standardized testing, you know, you're looking for data. But the key is why? What's it going to do for you? If you're provided time to deal with that data, that might then inform your instruction." – John [2 of 7]
Statistical literacy (Shield, 2004; Gould, 2017)	"I think, you know, being able to work with statistics, and gain knowledge about how statistics can be used." – Jim† [2 of 7]
Communicate findings (Gibson & Mourad, 2018)	"To be able to communicate that data to different organizations or people that are going to use that data to make decisions." – Peggy [1 of 7]
Ability to recognize and react to disinformation, misinformation and mal-information (Carmi et al., 2020)	"They have to know how to research sites that are real sites and not fake sites or not giving biased information." – Peggy* [1of 7]
Abiding by the ethics of handling data (Schield, 2004)	None

*Answer given in response to a question about authentic context.
† Answer given in response to a question about quantitative reasoning.

Table 3: Teacher data literacy descriptions compared to academic definitions. At least one teacher description of data literacy aligned with all but one of the academic descriptions.

4.3 Authentic context

Teacher responses to questions about authentic context were nearly as rich and detailed as their descriptions of data literacy. Their responses often emphasized the importance of building data skills by working with real, messy data that the students could relate to on a personal level, either because they gathered it themselves or it related to their day-to-day lives. Of the five academic definition themes relating to authentic context and authentic data, four were present in the teacher responses.

4.3.1 Authentic context description predominant codes

Teacher responses to questions about authentic context frequently dealt with building students' positive emotions about research. They felt that authentic context was an opportunity to make learning meaningful to students by engaging in authentic research. They also felt that authentic research was a way to teach students about the unknown nature of science.

4.3.1.1 Students conducting authentic research

Every teacher interviewed felt that authentic context involved the students conducting authentic research themselves. Many described authentic research as having the students gain realistic experience or "Getting them up, the hands on, the experiential… we're getting them out on the water, or in the water," as John put it. Other teachers described having the students design and conduct their own experiment from beginning to end, including asking an investigative question, designing an experiment, collecting data, and analyzing and interpreting data. Of those tasks, analyzing and interpreting data was mentioned most often, frequently in conjunction with a graphing activity. Roger discussed a task in which students were "making sense of the data by incorporating it into some graphing program, and then analyzing the data and seeing if there is a relationship that's meaningful, if it's significant." In addition to naming tasks traditionally associated with scientific research, four teachers described conducting authentic research as an opportunity for students to learn to cooperate with others. Susan mentioned an instance in which her students were forced to work together while gathering data, “Yes, they’re dropping lines, but they’re learning how to work as a team.” The teachers recognized that authentic research is an opportunity for students to *do* science within a collaboration, not just learn about it.

4.3.1.2 Meaningful to student

Of the seven teachers, three considered authentic context as a way to make the material meaningful to students. Meaning could be derived in different ways, whether it was because the topic related to the students’ daily experience, was a subject of particular interest for students, or it appealed to students’ emotional sense of place. Susan put it most succinctly when she said, “[Authentic context] means just engaging them in things that are meaningful to them, either because they’re interested or because it’s in their community, or because it’s something that impacts their day to day lives.” Other teachers provided similar responses as Kitty did when she stated that authentic context “is to make sure that they’re engaging in research that matters to them and to their community.” In this sense, authentic context is a way to help students engage with material by making it relevant to the world in which they live.

4.3.1.3 Unknown nature of science

Three of the interviewed teachers felt that authentic context was a way to introduce students to the unknown nature of science, whether that was through engaging in activities that do not have a textbook “correct” answer or understanding science as a process, not a cookbook-style list of instructions. Nancy offered a situation in which her students were forced to deal directly with the nature of science stating, “It’s not a cookbook lab where they’re like ‘Well, is that correct?' You know, 'Is my data right?' 'Well, your data is what you got.'" Kitty also related how her students struggled with the nature of science:

> "Just because you didn't necessarily answer the question you set out to, doesn't mean that it was a waste of time. The students…really struggle at, like, if they feel like they didn't meet the objective that was set out, it was just all for not."

So often, high school science labs are designed with certain results in mind. Enabling students to work within an authentic context is an opportunity for them to come to terms with science as practice without an answer key.

4.3.2 Code co-occurrence and grouping in authentic context

During data analysis, two interesting instances of code co-occurrence came to light. First, the two teachers who specifically talked about developing a scientific or investigative question also mentioned having the students participate in experiment design. As might be expected, these two science teachers perceived asking an appropriate question as an integral part of developing a scientific research project. Secondly, all teachers who discussed incorporating student research within a larger project also mentioned authentic context as an opportunity for students to collaborate with others. In both cases, they mentioned the two topics in separate thoughts. Integrating student research as part of a larger project was not specifically talked about as collaborating with others. Regardless, the teachers gravitated toward the idea of authentic context involving groups of people working together rather than individuals working alone.

Two instances of teacher grouping emerged in response to authentic context questions. The three teachers most closely associated with traditional science education, Roger, Nancy, and Kitty, all saw authentic context as an opportunity to develop student understanding of the unknown nature of science. None of the teachers involved in less traditional science education or social studies made the same connection. On the other hand, three teachers felt that a significant part of authentic context was to make the research meaningful to students. Of those three, only Kitty teaches in a traditional science classroom. The other two, John and Susan, teach in social studies and an alternative education program, respectively.

4.3.3 Teacher descriptions of authentic context compared to academic definitions

When describing authentic context, every teacher mentioned involving students in the process of authentic research from asking a scientific question to gathering and analyzing data to drawing conclusions. However, only five of the teachers mentioned bringing real-life experiences into the classroom. Table 4 shows how teacher descriptions relate to the themes from academic definitions. More than half the teachers talked about students collecting their own data, but only two discussed students collecting data in collaboration with others. Likewise, only two teachers mentioned using authentic context to engage students with actual scientific research. Although teachers touched on every academic definition theme except one, they were more focused on students collecting data independently and using it in the classroom than they were enabling the students to work with others as part of a scientific research project.

Authentic Context	
Academic Definition Theme	**Example Quote [# of teachers who mentioned the theme]**
Real-life experiences brought into classrooms (Kjelvik & Schultheis, 2019)	"They're learning about solar power and then we talk about how it relates to where we live and what's happening around us and they're doing research around that. How much energy does your home use?" – Susan [5 of 7]
Students collecting their own data (Gould, 2014)	"Having the kids work to collect the data, actually collect some of the information, maybe do a little bit of the background research." – Nancy [4 of 7]
Students engaging with data sets regarding actual scientific research (Kerlin et al., 2009)	"To me that would be having a question that researchers actually work on, because we don't have a solid answer to it yet." – Nancy [2 of 7]
Students collecting data in collaboration with others (Gould, 2017)	"Then, to make it truly authentic, it'd be really cool to incorporate it into a bigger body of research in collaboration with scientists and the research they're doing." – Roger [2 of 7]
Students using authentic secondary data (Kastens et al., 2015)	None

Table 4: Teacher authentic context descriptions compared to academic definitions. At least one teacher description of authentic context aligned with all but one of the academic descriptions.

4.4 Quantitative reasoning

Of the three concepts, teachers struggled most with quantitative reasoning. Many stated that it dealt with numbers and numerical reasoning, but few offered the rich descriptions and examples given for authentic context and data literacy. Despite their brevity, teacher responses encompassed four of the five academic definition themes.

4.4.1 Quantitative reasoning description predominant codes

Two of the three predominant codes that arose when teachers were asked about quantitative reasoning dealt with using number-based data to find meaning and solve real-world problems. The third theme, lack of teacher knowledge, provides some insight into how unfamiliar teachers are with the concept of quantitative reasoning.

4.4.1.1 Quantitative interpretation and analysis of data

The code quantitative interpretation and analysis occurred nine times during the teacher interviews. However, it is worth noting that all nine instances came from the three teachers who provided the most multifaceted descriptions of quantitative reasoning. Types of interpretation and analysis included relational/proportional reasoning, reasoning with numbers, numerical descriptions, and determining relationships between variables. When responding to the question, Roger listed several terms without providing any amplifying information. He stated, "There would have to be … some kind of relational reasoning, proportional reasoning, reasoning with numbers, in order to describe a relationship." Nancy and Jim both delved into the idea of numerical descriptions a little more deeply, giving a classroom example of encouraging students to think quantitatively as well as qualitatively. Nancy described quantitative interpretation as "Using numerical descriptions of whatever you're working on as opposed to just kind of describing it. The kids tell you, 'It's fine.' Okay, how fine is it? Right? Give me some numbers." Similarly, Jim described quantitative analysis as, "Looking at a field or study that you want to do, and finding ways to measure it as opposed to just have kind of a qualitative feel for, say, the effects of water rising." In these descriptions, quantitative reasoning has several aspects, all of them related to comparing numeric quantities.

4.4.1.2 Real-world applications

Two teachers thought about quantitative reasoning in a real-world context, albeit in two different ways. John related student-gathered data to a larger body of data. "What does that mean in the bigger picture of something? So, water temperatures in the Penobscot Bay – well, alright, let's look at it historically. Okay, maybe we can determine and predict possibly what might be coming then." Kitty, on the other hand, considered applying quantitative reasoning to questions in the classroom:

> "So, if we're working with our fish tanks and we're doing water quality testing, and we see that we have a pH that's out of balance… What do we need to change to bring the pH up or down, however much we need to?"

These answers imply some of the teachers saw quantitative reasoning as something that required authentic context, not just a theoretical exercise.

4.4.1.3 Teacher lack of knowledge

Two teachers expressed a lack of understanding about quantitative reasoning. Neither was confident enough in their knowledge to provide an answer. When asked what quantitative reasoning meant to them, Susan simply responded, "Absolutely nothing." Peggy said, "I don't know. I don't know the answer to that. I don't know what that means." The two teachers who described a lack of knowledge about quantitative reasoning were the most experienced and least experienced teachers. Additionally, neither Susan nor Peggy taught in a traditional science classroom: one taught alternative education, the other technology. They are also two of the oldest teacher participants in the study. Although only two of the teachers explicitly stated they did not know anything about quantitative reasoning, the brevity of the other teachers' answers suggests they all lacked a robust understanding of the topic.

4.4.2 Code grouping in quantitative reasoning

When asked about quantitative reasoning, teachers tended to fall into one of two groups. In one group, two teachers discussed numerical reasoning using more abstract, hypothetical language. They listed the mathematical skills a student might need for quantitative reasoning, but not how they would be applied. In the other group, three teachers described using quantitative reasoning for real-world applications. Some of them mentioned taking measurements, but none of them referred to any abstract mathematical concepts. The teachers who were most concerned with abstract mathematics both teach in traditional science classrooms. Those that thought of quantitative reasoning as a concept concerning real-world applications came from a variety of backgrounds including traditional science teacher, engineering, and social studies. Teacher responses concerning quantitative reasoning did not show any significant code co-occurrence.

4.4.3 Teacher descriptions of quantitative reasoning compared to academic definitions

Teacher answers to questions about quantitative reasoning were the least detailed of all the topics. They mention all but one of the themes present in the academic definitions, but not with the same depth as in the other concepts. Additionally, Table 5 indicates a smaller number of teachers mentioned each academic definition theme compared to data literacy and authentic context. The lack of robust quantitative reasoning descriptions is evident in how teacher descriptions touch on only a small aspect of each academic description. For example, the one teacher who mentioned using mathematical skills for problem solving did not refer to the complexity of the problem or the sophisticated manner in which mathematical principles might be used. In another example, a teacher lists several skills that he considered part of quantitative reasoning, but did not discuss under what circumstances those skills might be employed. Only two of the teachers considered quantitative reasoning in terms of real-life issues and contexts, a central aspect to every academic definition. None of the teachers thought of quantitative reasoning as a habit of mind. Instead, they looked at a student's quantitative reasoning abilities as a set of necessary skills to be used to analyze, interpret, and solve numeric problems.

Quantitative Reasoning	
Academic Definition Theme	**Example Quote [# of teachers who mentioned the theme]**
Required skills: arithmetic, measurement, percentages, graphs, probabilities and statistics, growth patterns (Hallett, 2008, as cited in Grawe, 2011)	"So, it could be via percentages… proportions or something like that. Like, you know, this is whatever – two thirds of this." – Roger [3 of 7]
Real-life issues and contexts (Steen, 2001)	"So, water temperatures in Penobscot Bay – well, alright, let's look at it historically. Okay, maybe we can determine and predict possibly what might be coming then." – John [2 of 7]
Communicating findings or intended actions (Mayes, 2013)	"I enjoy putting it into the bigger picture, and then maybe translating that to, 'This is why we collect it. Because it affects you, Joe [town] citizen, looking out over the harbor about water temperatures and long-term effects of this or that.'" – John [1 of 7]
Using mathematical principles in a sophisticated manner to solve complex problems (Wilkins, 2000)	"That means that students should be able to look at a problem that they're facing and think about how they can use the values they they're seeing as a way to understand what they're looking at, and how to solve problems using that." – Kitty [1 of 7]
Habit of mind, way of thinking (Grawe, 2011)	None

Table 5: Teacher quantitative reasoning descriptions compared to academic definitions. At least one teacher description of quantitative reasoning aligned with all but one of the academic descriptions.

4.5 Relating authentic context and quantitative reasoning to data literacy descriptions

According to the framework established by Kjelvik and Schultheis (2019), data literacy is closely related to both authentic context and quantitative reasoning. When codes drawn from each concept were compared, a significant overlap between authentic context and data literacy emerged. Quantitative reasoning, on the other hand, appeared to overlap only slightly with teacher perceptions of data literacy.

4.5.1 Comparing authentic context and data literacy

Asking the teachers about authentic context elicited rich descriptions with many examples. From their answers, teachers were clearly eager to increase students' interest and involvement with science while building their data literacy skills. As a group, teachers saw the two topics as closely related as evidenced by the number of similar codes that arose between the topics. Codes emerged relating to students collecting data, data interpretation and analysis, the unknown nature of science, and communicating using data under both data literacy and authentic context. As individuals, the teachers also seemed to envision significant overlap between data literacy and authentic context. Of the six teachers who mentioned data interpretation and analysis while discussing data literacy, four of them also mentioned it when speaking about authentic context. Similarly, three of the five total teachers who talked about students collecting data did so while talking about both data literacy and authentic context. Those codes that aligned with fewer teacher responses indicated less overlap on an individual level. For example, the one teacher who saw communicating with data as part of data literacy was not the same teacher who associated communicating with data as part of authentic context.

Authentic context and data literacy descriptions also both included an aspect of making science topics more engaging for students. In authentic context, this included finding subjects that were meaningful to students by relating them to students' community and everyday life. When discussing data literacy, teachers related using data for real-world applications and issues that affect students' lives, such as rising sea levels in a coastal town. From their descriptions of the two concepts, teachers' perceptions of authentic context and its importance in the classroom overlap a great deal with their descriptions of data literacy.

4.5.2 Comparing quantitative reasoning and data literacy

Teachers provided the shortest, least descriptive answers when asked about quantitative reasoning. Only one mentioned a specific example of using quantitative reasoning in her classroom. The teachers' responses indicate far less overlap between quantitative reasoning and data literacy than between authentic context and data literacy. There was only one code in which teachers showed significant overlap, both as a group and individuals: using data or quantitative reasoning for real-world applications. When discussing data literacy, five teachers mentioned using data for real-world applications. Three of those five also talked about real-world applications when asked about quantitative reasoning.

At first glance, the data literacy child code “data interpretation and analysis” seems to suggest a great deal of overlap with the quantitative reasoning child code “quantitative interpretation and analysis”. However, the topics teachers mentioned within those child codes and the child subcodes that emerged from teacher discussions indicate that the two codes are less related than might be assumed. When discussing data interpretation and analysis under data literacy, teachers talked about visualizing data both by having students create their own graphs and interpret the graphs of others. Teachers also mentioned dealing with messy data that includes outliers and data gaps. Lastly, they talked about extracting meaning and drawing conclusions from data. On the other hand, when teachers spoke about quantitative interpretation and analysis of data, they talked mainly about using numbers to describe and compare data. Their descriptions focused on using quantitative, rather than qualitative measures to label data. One teacher did mention extracting facts from data when discussing quantitative reasoning, but extracting facts is not the same as extracting meaning.

Several of the teacher responses to questions about data literacy included aspects of quantitative reasoning skills, such as graphing and communicating with data, but those same skills were rarely mentioned when discussing quantitative reasoning. Only one teacher mentioned graphing when discussing both data literacy and quantitative reasoning. Similarly, only one teacher mentioned communicating with data when asked about quantitative reasoning, but he did not mention communication while talking about data literacy. Overall, the teachers' answers indicate that they perceive some overlap between data literacy and quantitative reasoning, particularly with regard to using data in real-world situations, but less overlap than between data literacy and authentic context.

4.5.3 Data literacy, authentic context, and quantitative reasoning together

The teachers gave the richest, most detailed descriptions when discussing data literacy. Their comments included aspects of both authentic context and quantitative reasoning. However, where the authentic context ideas mentioned in data literacy were also largely present in authentic context descriptions, the quantitative reasoning concepts described during the data literacy portion of the interview were not strongly reflected when discussing quantitative reasoning. Three teachers brought up data science topics when discussing data literacy despite not being asked about data science directly. None of them mentioned anything as sophisticated as the programming or development of digital tools described by Finzer (2013), but they all talked about students gaining basic computer skills using programs such as Google Sheets or Microsoft Excel.

The teachers' perceptions of data literacy differ significantly from the framework presented by Kjelvik and Schultheis (2019). In the teachers' descriptions, data literacy is its own entity instead of existing at the intersection of data science, authentic context, and quantitative reasoning (Figure 2). In the teachers' descriptions, data literacy overlaps a great deal with authentic context. It also overlaps with data science, although the degree to which the two are connected cannot be determined because teachers were not explicitly asked about data science. The teachers' descriptions indicated that they perceived very little overlap between quantitative reasoning and data literacy. Three of the teachers did describe quantitative reasoning in terms of real-world applications, which indicated a link between quantitative reasoning and authentic context. The result of these descriptions is not the tidy, symmetrical Venn diagram offered by Kjelvik and Schultheis (2019). Rather, it is a lopsided Venn diagram in which authentic context and data literacy overlap a great deal and quantitative reasoning hardly at all. The sparse descriptions of quantitative reasoning also suggest a smaller input to the Venn diagram that only relates tangentially to authentic context or data literacy.

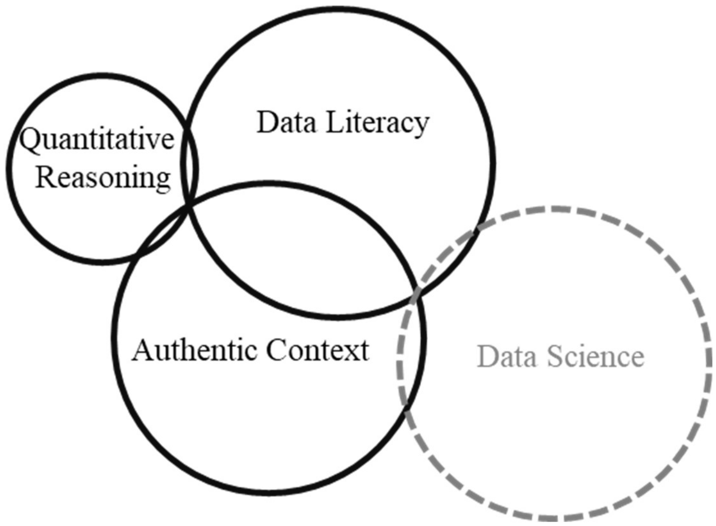

Figure 3: Teacher descriptions of data literacy concepts. In teacher descriptions, data literacy and authentic context are closely related. Quantitative reasoning has very little overlap with the other two concepts. Some teachers mentioned data science, but it was not explicitly asked about in this study.

CHAPTER 5

DISCUSSION AND IMPLICATIONS

5.1 Teacher responses

When teachers answered questions about the data literacy concepts, they tended to answer in terms of their students, either desired student outcomes or classroom activities that served as examples. Of the 28 scripted questions asked of teachers, they answered 17 of them with student-centric responses. Perhaps more tellingly, four of the teachers, Peggy, Susan, Nancy, and Kitty, gave student-related responses to at least three of the four questions. This may be because the interviewer directed the teachers to “tell me what each of these processes mean to you as a classroom instructor”, thereby putting them in a frame of mind to answer as a teacher instead of as a member of the general public. However, the other teachers only mentioned students in one or two responses.

As they discussed the data literacy concepts, teachers often mentioned skills they felt students should possess in order to be data literate. These skills largely match the codes assigned to teacher responses with a few exceptions in which teachers discussed topics other than desired student outcomes. Teachers thought that students should be able to design an experiment with an appropriate question or goal, collect and organize data, analyze and interpret the data, create a graphical representation of the findings, and communicate those findings with others. They also felt that students should be able to recognize the real-world meaning and ramifications of data. Other skills mentioned less often included recognizing misinformation and using mathematics skills for problem solving in daily life.

5.2.1 Teacher descriptions of data literacy

There appears to be no end in sight to the growth of the data industry in today's society. As young individuals who have access to unimaginable amounts of data on a daily basis, students must learn to process and react appropriately to data. Scientists, too, face increasingly large and complex data sets (Baker, 2017). As a result, science classrooms must expose students to large, authentic data sets to build the data skills necessary to thrive not only in STEM careers, but as discerning citizens (Cook, et al., 2014; Mayes et al., 2014). To teach students, educators must have a solid understanding of data literacy concepts, which requires professional development support for both pre-service and in-service teachers. At present, research offers a variety of lesson plans, unit plans, and other suggestions on how to implement data literacy in classrooms, but there is little research on the Pedagogical Content Knowledge (PCK) needed to help students develop their data literacy skills (Miller, 2022). If teacher educators are to determine the PCK skills necessary and help teachers build them, they must be cognizant of teachers' current perceptions of data literacy. This study sought to determine how teachers think about data literacy and its related concepts, authentic context and quantitative reasoning.

As a group, teachers provided robust descriptions of data literacy that all matched some aspect of definitions found in recent literature, suggesting that the pushes for greater data literacy education in science have made their way into high school and middle school classrooms. Teachers exhibited a broad understanding of data literacy and easily discussed data literacy in their own curricula. For the most part, teacher descriptions of data literacy centered around students collecting and interpreting data. Their descriptions also emphasized the importance of maintaining a link between data and real-world applications. They encourage their students to see data as information that has implications for everyday life, not as an abstract concept.

In addition to descriptions largely focused on students dealing with data in a scientific research sense, several teachers also mentioned aspects of data literacy not commonly associated with a science classroom, such as recognizing misinformation and disinformation for what they are. This indicates that some teachers recognize data literacy as a life skill for all citizens, not simply a skill for STEM students.

With one exception, teachers did not mention communicating information to others via data. Instead, teachers focused on students building their own knowledge of data, by both creating visualizations of data and finding meaning in data. This suggests that teachers are enabling students to understand the language of data and scientific discourse as a stepping stone to entering the conversation fully. Unfortunately, based on the teachers' answers, it is not clear when they would expect students to make the leap from absorbing the data presented to communicating their own scientific information.

Future professional development efforts might seek to capitalize on teacher prior knowledge of data literacy by helping teachers to continue to create lessons in which students work with authentic data. Professional development might also seek to continue to expand teacher understanding to include identifying misinformation and disinformation. With the rise of questionable science-related articles available from the media, teachers have ample opportunities to expose students to authentic examples of misinformation. Teachers could then expand student data literacy skills by helping them ask cogent questions to determine the validity of a scientific argument. There are a variety of methods teachers might use to aid students in identifying misinformation, including Blakeslee's (2004) aptly acronymed "CRAAP Test". Lastly, professional development might suggest some ways in which students could enter into the scientific conversation by presenting data they had worked with and communicating their findings.

5.2.2 Teacher descriptions of authentic context

Teacher discussions of authentic context were nearly as robust as those concerning data literacy. The teachers provided many detailed classroom examples and were clearly eager to engage students' interest. Interestingly, teachers also saw authentic context as a way to introduce students to the unknown nature of science and move away from the textbook labs with traditional right and wrong answers. The teachers' emphasis on including authentic research that is meaningful to students indicates a strong perceived link between authentic context and data literacy. When asked about either concept, teachers' answers contained strong themes of students working with authentic data that relates to real-world applications.

Recent literature includes many recommendations on how to incorporate authentic context into the classroom, from merging data with other sources (Kastens et al., 2015) to incorporating large data sets from distant sensors (Gould et al., 2014). However, these lesson plans tend to be globalized so they could be used with equal ease in any town or region. Little of the literature describes how teachers could incorporate local data sets that pertain to the immediately surrounding area. Literature about place-based learning provides lists of common elements, best practice examples, and the philosophy behind place-based learning (Smith, 2002; Gruenewald 2003), but little practical advice on how to establish a place-based unit or curriculum. Professional development programs might help teachers recognize sources of data in their communities and determine how to bring them into the classroom. Professional development of this nature would need to be location-specific and tailored appropriately, but could potentially aid teachers in engaging student interest. Local authentic context can engage students' attention through data that relates to students' everyday lived experience. Localized professional development could also facilitate opportunities for collaboration between teachers and local partners. In this way, students could become involved, not only with authentic data, but real scientific research that may affect their community.

5.2.3 Teacher descriptions of quantitative reasoning

Teachers struggled most when discussing their perceptions of quantitative reasoning. Two were unable to give any description at all. Those that did offer descriptions provided less insight and fewer concrete classroom examples than they did for data literacy and authentic context. Teachers mentioned some topics associated with quantitative reasoning, such as interpreting graphs, when asked about data literacy, but not when asked about quantitative reasoning. This indicates a lack of understanding of what topics quantitative reasoning includes. Their in-depth discussion of graphing skills indicates that teachers understand quantitative reasoning concepts and their importance, but they do not recognize them as quantitative reasoning. This may because most of the teachers specialized in science, rather than mathematics. The majority of research concerning teacher quantitative reasoning skills involves mathematics teachers not science teachers (Stump, 2017; Webber et al., 2014).

When discussing the data interpretation and analysis aspect of quantitative reasoning, teachers focused mostly on numerical reasoning such as proportional reasoning and numerical descriptions. Those teachers who mentioned numerical reasoning tended to do so in an abstract sense. They did not link quantitative reasoning with authentic context the way they did data literacy. Other teachers did mention real-world applications, but did not mention numerical reasoning skills. In this instance, there appears to be a divide within the group between teachers who associate quantitative reasoning with abstract numerical processes and those who see quantitative reasoning as closely associated with everyday experiences.

Although some teachers named problem solving as a key aspect of quantitative reasoning, none of them mentioned the key tenet of quantitative research that is using mathematics skills to solve complex, open-ended problems. The generic topic of problem solving provided by the teachers is certainly relevant to quantitative reasoning, but the lack of specificity fails to recognize the real-world problem-solving aspect so inherently tied to quantitative reasoning.

If teacher educators wish to see more quantitative reasoning in science classrooms, they will first need to define quantitative reasoning in terms of science education. As is evident in this study, teachers frequently do not associate quantitative reasoning concepts with the phrase "quantitative reasoning." This may be because most teacher training in quantitative reasoning is focused on mathematics teachers (Glassmeyer, 2019; Moore et al., 2014) or it may be because teachers, in general, lack quantitative reasoning skills (Cowie & Cooper, 2017). Once teachers have a better understanding of what quantitative reasoning includes, professional development can help them create units and lessons that embrace open-ended problem solving in a scientific context.

5.3 Limitations

The teachers in this study self-selected based on an interest in improving how they teach data literacy in their classrooms. Joining the study alone indicates an interest in the topic and a dedication to practice improvement. Before their involvement with the research practice partnership (RPP), all of the teachers participated in the *Maine Data Literacy Project*, albeit to varying degrees. As a result of their interest and prior experience, they may have had a better understanding of what data literacy is and how it can be integrated into a classroom than a teacher without the same background. Interviews conducted with teachers who do not have any previous experience with data literacy may not elicit the same rich responses received from this cohort.

This study was also limited by the small sample size of teachers interviewed. Ten teachers joined the first RPP cohort, but only seven were available for initial interviews over the summer, which falls short of the 20 interviews necessary to achieve 97% theme saturation in a qualitative study (Turner-Bowker, 2018). Even Saldaña's (2016) more modest recommendation of a minimum of 15 interviews for a grounded theory study is over twice the number of interviews available for this study. The teachers also represent a fairly homogeneous group in that they all come from the same school district. Other districts may not encourage opportunities for students to get out of the classroom and into the surrounding community as the RPP school district does. All but one are science teachers and all but one teach at the high school age level. Including math teachers or additional teachers from the humanities may have affected how the group as a whole described the concepts. Given the greater emphasis on quantitative reasoning in math teacher preparation (Piatek-Jimenez, et al., 2012; Stump, 2017), math teachers may have provided more robust descriptions of quantitative reasoning. Interviewing more social science teachers may have provided broader perspectives on how data literacy and authentic context might be included in classrooms. Including more middle school teachers may have offered better insight on what teachers feel are age-appropriate applications of data literacy.

5.4 Future research

Since the teachers in this study are part of an ongoing professional development project, future researchers may have the opportunity to determine how teacher perceptions and descriptions of data literacy, authentic context, and quantitative reasoning change over the course of the project. Specifically, does participating in such a project deepen the teachers' understanding of quantitative reasoning and all that it involves? Do teacher views on the relationships between data literacy, authentic context, and quantitative change? The RPP offers a unique opportunity to explore how teachers adapt their perspectives as the result of professional development.

On a broader scale, more research is required into what PCK is required for middle and high school educators to effectively teach data literacy. Lesson plans are a useful and helpful start, but often focus on a single subject and so do not include the interdisciplinary nature of data literacy. As a result, those lesson plans cannot encompass the entirety of PCK necessary. As researchers gather more information on data literacy PCK, parallel research must examine how to help teachers reach a sufficient level of PCK to integrate data literacy into their classrooms and school-wide curricula. Together, these two lines of effort can develop effective pre-service training and in-service professional development programs to assist teachers in creating classrooms designed to increase student data literacy.

5.5 Conclusion

The goal of this study was to determine how in-service middle and high school teachers describe the STEM-related concepts of data literacy, authentic context, and quantitative reasoning. The study compared teacher descriptions to academic definitions and determined how teacher understanding of authentic context and quantitative reasoning informed their descriptions of data literacy.

Teachers offered rich, closely-related descriptions of data literacy and authentic context with many classroom examples. Their discussions of data literacy and authentic context contained significant thematic overlap. When asked about quantitative reasoning, teachers had difficulty providing the same robust descriptions or classroom examples. Their answers indicated very little overlap between data literacy and quantitative reasoning. Teachers seemed to view data literacy and quantitative reasoning as two separate topics rather than related concepts. They are less comfortable with the idea of quantitative reasoning. Even though the teachers are well versed in many aspects of quantitative reasoning, they do not recognize it. As a group, the teachers' descriptions covered almost every aspect of the academic definitions, even those outside the scope of a typical science classroom. Individually, ideas within teachers' answers varied a great deal, but were all related to some facet of the academic definitions.

The results suggest teachers hold strong perceptions of data literacy, authentic context, but less so for quantitative reasoning. If teacher educators wish to prepare effective training strategies to help teachers achieve the interdisciplinary PCK necessary to build student data literacy skills, they must be mindful of teacher perceptions. Building on teacher perceptions may help create a deeper understanding of data literacy concepts, including how to include them in day-to-day classroom activities.

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APPENDIX A: INTERVIEW PROTOCOL

Thank you very much for being willing to do this interview today! Before we start, I'd like to walk through the informed consent for this project. This is part of the process of doing research that involves gathering data from or about people.

Informed consent process (walk through the informed consent document prior to beginning the interview – offer an opportunity for questions/discussion about the research)

Is it ok to record this interview?

This interview will ask about your teaching background and experience, as well as your thoughts and reflections on various target practices that we are integrating in this project. There are no right or wrong answers to these questions; we simply want to understand your current thinking on these topics.

Do you have any questions before we begin? Ok, I'll go ahead and begin. First, we'd like to ask some general questions about your background and understanding of the project.

<u>Background information</u>

1. What do you currently teach and how long have you been teaching?
2. What was your background prior to teaching?
3. What knowledge, skills, experiences, or other strengths are you bringing to contribute to this project?
4. (All years) What is your current understanding of the project and its goals?
5. What motivated you to participate in this project? What do you hope to gain?
6. What previous experience have you had working in partnerships with University researchers?
    a. What benefits do you anticipate from this partnership work?
    b. What challenges do you foresee for the project?

We'd now like to ask you about how you currently think about certain target practices this project is aiming to integrate into the classroom experiences you will be developing.

<u>Conceptualizing & Implementing Target Practices</u>

1. Please describe what the following processes mean to you as a classroom instructor: (show the following list on-screen)
    a. Engaging students in authentic research
    b. Engaging students in place-based learning
    c. Working with data
    d. Applying data literacy skills
    e. Reasoning quantitatively

<u>Follow up:</u>

    f. What are the technology tools and/or technological skills that you think students need to know in order to engage in these practices?

    g. Could you provide an example of how you currently address any or all of these practices in your classroom?

2. Our project work is situated within a coastal, marine science context. In your view, please describe what the discipline of “marine science” includes.
3. Imagine your students are asked to conduct research to answer a driving question for your class. What scaffolds or supports would you provide to them as they engaged in this process?
4. Beyond content knowledge, our project aims to build “soft skills” in students for career readiness. These skills could include things like problem-solving, perseverance, communication, ability to navigate available resources independently, determining reliable sources, or teamwork, etc.
    a. Which soft skills do you think are especially important in the context of this project?

We’d now like to ask you about the project as a whole and your participation in it. This project is a research-practice partnership, or RPP, which means we have university researchers working closely alongside teachers - or practitioners - like you to work collaboratively to address problems of practice. The project team is therefore composed of education researchers from the RiSE Center, other university researchers with specific areas of expertise (like marine science), teachers from across RSU 71, and, eventually, community partners supporting our work.

The following questions will ask about your perceptions of your personal role within this larger project context.

Project Reflection:

1. Has the organization and implementation of project activities (e.g. communications, project staff support, meeting coordination, etc.) been sufficient to support your participation in the project?
    a. What enables or constrains you to participate in project activities?
2. Do you feel empowered to communicate your ideas to the rest of the team during project meetings and activities?
    a. Do you feel your ideas are heard/valued by the project team?
3. What do you envision as success for the overall project?
4. What would success look like for you personally in this project?
    a. How do you envision success for students in this project?
5. Do you have any concerns or questions?
6. What has excited you about this project?

Thank you very much for participating in this interview! We’re looking forward to continuing our work with you in the coming year! Do you have any other questions for me at this time?

APPENDIX B: CODE BOOK

- Parent Code
    - Child Code
        - Child Subcode
- Data literacy
    - Applying computer science skills
    - Applying mathematical principles
    - Collecting data
    - Communicating information via data
    - Data interpretation and analysis
        - Creating a visual representation of data
        - Dealing with messy data
        - Drawing conclusions from data
        - Extracting meaning from data
        - Interpreting graphs
        - Remaining objective
        - Unknown nature of science
        - Using data to answer questions
    - Identifying the purpose of data
    - Managing data
    - Teacher difficulty
    - Teacher requests clarification
    - Using data for real-world applications
    - Using data to inform teaching practices (DLFT)
- Authentic context
    - Incorporated into a larger project
    - Learning extends to other areas
    - Maintaining teacher enthusiasm/interest
    - Meaningful to student
        - Place-based
        - Relates to students' daily experience
        - Student interest
    - Project based
    - Students conducting authentic research
        - Analyzing and interpreting data
        - Asking an investigative question
        - Collaborating with others
        - Collecting data
        - Communicating their conclusions
        - Designing an experiment

- Students learning about authentic research
- Unknown nature of science
  - Lack of textbook "correct" answers
  - Science as a process, not a list of instructions

- Quantitative reasoning
  - Making data relevant to the layperson
  - Quantitative interpretation and analysis
    - Extracting facts from data
    - Numerical descriptions
    - Reasoning with numbers
    - Relational/proportional reasoning
    - Using quantitative vs qualitative measurements
  - Real-world applications
  - Teacher lack of knowledge
  - Using current data to inform future research
  - Using mathematical reasoning for problem solving
  - Working with statistics

BIOGRAPHY OF THE AUTHOR

Originally from Winchester Bay, Oregon, Madeline Dougherty graduated from the United States Naval Academy in 2007 with a Bachelor's of Science in Oceanography. She commissioned into the United States Marine Corps and served over nine years on active duty as a helicopter pilot. Since leaving active duty in 2016, she has worked as an airline pilot, flight school curriculum content writer, government contractor, and helicopter air ambulance pilot. She continues to serve in the Navy Reserves. Madeline is a candidate for the Master of Science in Teaching degree from the University of Maine in May 2024.