QUANTITATIVE LITERACY IN GENERAL EDUCATION SCIENCE COURSES AT A COMMUNITY COLLEGE: STUDENT AND INSTRUCTOR REPORTS

By

Richard A. Edwards

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Mathematics Education—Doctor of Philosophy

2016

ABSTRACT

QUANTITATIVE LITERACY IN GENERAL EDUCATION SCIENCE COURSES AT A COMMUNITY COLLEGE: STUDENT AND INSTRUCTOR REPORTS

By

Richard A. Edwards

Research indicates that significant numbers of community college students enroll in quantitative literacy (QL) courses, yet we know little about the quantitative experiences of these students after they complete QL coursework. This qualitative case study was designed to explore with a sample of community college students and science instructors connections between general education science courses and the students' QL course. The rationale for this study emanates from the researcher's desire to uncover new ways of describing the role of QL courses in preparing students for further academic study. The sample was composed of six community college students and five science instructors. The primary data collection method was in-depth interviews. Supportive methods included demographic surveys, a focus group, and a document review. This research revealed that (1) students are able to make many connections between tasks in a QL course and tasks in a subsequent science course, (2) student and instructor descriptions of science tasks emphasize data analysis and representation, and (3) student descriptions of science tasks included more references to higher order quantitative thinking than science instructor descriptions of science tasks. Recommendations are offered for QL curriculum writers and instructors, for mathematics and science instructors, and for further research.

For Megan and Paul, with love.
For Granddad, we will see each other again one day.

ACKNOWLEDGEMENTS

I would like to thank Vince Melfi, Brin Keller, Sharon Senk, and Gabe Ording for their help and encouragement throughout this process and throughout my time at Michigan State University. Thanks to the Quantway instructors who helped with recruiting students, allowed me to observe their classrooms, and for their intellectual guidance. Thanks to the Carnegie Foundation for the Advancement of Teaching, for proving digital copies of their curricular materials. Thanks to Luke Tunstall for help with coding. Thanks to the students and instructors who participated in this research—without your efforts the work could not have happened. Thanks to Megan Edwards for help in preparing the written dissertation and for moral support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I: INTRODUCTION

Quantitative literacy is a bridge to further learning. Steen (2004, p.9) argued that to be quantitatively literate in the twenty-first century, a person must possess “a new set of problem solving and behavioral skills that emphasize the flexible appreciation of reasoning abilities”. Hughes-Hallett (2003) suggested that the hallmark of quantitative literacy is not the amount of mathematics one understands, but how widely a person can apply the mathematics they do know. With that in mind, this study is focused on the phenomenon of how students and instructors perceive aspects of quantitative literacy (QL) in general education science courses. The purpose of this study was to explore with a group of community college students, and their science instructors, the quantitative literacy demands of general education science courses, and the ways in which students connect quantitative ideas across courses. The knowledge generated from this inquiry should afford new insights into the role of QL courses, highlight connections between QL and science instruction for non-STEM majors, and further polish existing theoretical lenses on how students connect mathematical ideas across different academic contexts. This study employed qualitative multicase study methodology to illustrate the phenomenon. Participants in this study included a purposefully selected group consisting of six community college students who completed a quantitative literacy mathematics course, and who were subsequently enrolled in general education science courses. Other participants included the instructors of the science courses in which these students enrolled.

This chapter begins with an overview of the context and background that informed the study. Following this is the problem statement, the statement of purpose, and accompanying research questions. Also included in this chapter is a discussion about the research approach, the researcher’s perspectives, and the researcher’s assumptions. The chapter concludes with a discussion of the proposed rationale and significance of this research study and definitions of key terminology.

Background and Context

A significant issue in community college mathematics education is how to best serve students who place into the lowest level of developmental courses. Nationwide, over half of all community college students who place into developmental mathematics courses never complete a college-level mathematics course (Hern & Snell, 2010; Hagedorn & DuBray, 2010; Aud, Fox, & KewalRamani, 2010), and thus never receive a college degree. Students from racial-ethnic backgrounds are disproportionately affected by multi-semester developmental course requirements, meaning that the same students who were underserved by their high school mathematics courses are denied access to college-level mathematics (Aud, Fox, & KewalRamani, 2010). The failure of many students to complete core mathematics requirements not only represents personal setbacks to individuals' pursuit of college education, but the situation is also wasteful in terms of resources, time, and money for institutions and departments (Bailey, Jeong, & Cho, 2010).

The typical curriculum and pedagogy found in developmental mathematics classes focuses largely on developing procedural skill efficiency, with less emphasis given to developing conceptual understanding (Goldrick-Rab, 2010). Unfortunately, many students who place into developmental mathematics courses are not motivated to learn these mathematical skills and procedures, in part because they do not consider such skills to have any connection with their personal lives or educational goals (Cavazos, Johnson, & Sparrow, 2010). There are no quick answers to the problems of developmental mathematics instruction in community colleges, but one popular trend in shifting the focus of developmental mathematics courses toward helping students develop quantitative literacy (QL).

QL courses are intended, in part, to prepare students for the kinds of quantitative reasoning they might experience in everyday life. Such reasoning might include interpreting the statistics in a physician's report, or making informed decisions as a voter (Steen, 2003). In contrast to Steen's vision of QL for all, QL courses have grown in popularity as alternatives to traditional mathematics coursework for students who do not intend to major in the sciences, technology, engineering or mathematics (STEM) fields (Blair, Kirkman, & Maxwell 2010). QL courses result in improved completion rates for developmental mathematics students (Carnegie Foundation for the Advancement of Teaching, 2012). In other words, the percent of students who pass QL courses at many institutions is higher than the pass rate in traditional developmental courses such as Intermediate Algebra (see also Clyburn, 2013; Hern & Snell 2010; Goldrick-Rab, 2010). In addition to allowing more students to complete their mathematics requirements, QL instruction is often promoted as preparing students for the quantitative demands of other academic subjects (Wolfe, 1993; Grawe, 2011; Steele & Kiliç-Bahi, 2008).

Educators outside mathematics departments are also interested in QL instruction. Efforts to improve students' QL are promoted by many different stakeholders, including instructors in partner disciplines such as the biological and physical sciences (Rheinlander & Wallace, 2011), social sciences (Caufield & Persell, 2006), and business (McClure & Sircar, 2008). A common theme across multiple QL curriculum initiatives (Carnegie Foundation for the Advancement of Teaching, 2012; Clyburn, 2013; Goldrick-Rab, 2010; Hern & Snell 2010;) is the notion that if the content of QL curriculum is chosen and taught appropriately, students will be more comfortable with similar mathematics and statistics when it appears in other contexts.

As with any educational endeavor, there are those who voice concern. For example, Sally (2003) argues against the notion of over-contextualizing mathematics instruction:

> This notion that one has to 'interest' students in mathematics in order to make them do it has gone much too far, to the point where real mathematics in many cases has just disappeared entirely from the courses. They're just a discussion of what mathematics does, or beautiful pictures and imprecise ideas.

Hayden (2004) echoed such concerns, warning that the biggest temptation in teaching a quantitative literacy courses is to teach watered-down versions of traditional mathematics content. Estry and Ferrini-Mundy (2005) report that such concerns represent a dominant theme in discussions surrounding QL instruction. Likewise, Fitzsimons (2006) reported on a trend toward diminishing the mathematics content in mathematics courses for non-STEM majors. His analysis led him to conclude that the decision to reduce the mathematics content in such courses was made primarily to improve completion rates – a metric that is often used to measure the success" of QL courses.

Although there has been a proliferation in the number of QL courses offered in institutions of higher learning in the past two decades (Dingman & Madison, 2010), there has been little research into the relationship between students' experiences in QL courses, and their experiences in subsequent academic courses. QL instruction, particularly as an alternative to traditional developmental mathematics courses, does seem to hold great promise for certain groups of college students, including the fact that students generally pass QL courses at higher rates than students typically pass developmental mathematics courses (Betne, 2010; Clyburn, 2013). What is less understood is the extent to which QL instruction prepares students for quantitative experiences in other courses. As a specific example, we have little research-grounded evidence that QL courses prepare students for the quantitative demands of general education science courses, even though such courses are frequently taken by the same non-STEM students.

In this study, I document the experiences of students who took a two-semester QL course called “Quantway” (described more thoroughly in the next chapter). One goal of Quantway is to prepare students for further academic study (Carnegie Foundation for the Advancement of Teaching, 2012). This notion was among several that originally motivated this dissertation research. Most, if not all published research on Quantway—and to a large extent on QL courses in general—is bounded by time and stops the moment a student completes a QL course. In this study, I explore the academic experiences of students post-Quantway. In particular, I wished to know when and how students perceive aspects of QL in subsequent science courses, and also the ways in which community college science instructors perceive aspects of QL in their courses.

By exploring these issues, I hoped to further explicate (a) the QL demands of general education science courses as described by both students and instructors, (b) the opportunities these students have to engage in a variety of types of quantitative reasoning during their science courses, and (c) the ways in which students transfer understanding of mathematical concepts to a science context.

Problem Statement

Despite significant investment on the part of community colleges to implement QL courses, we do not know much about the academic experiences of students once they pass such courses. Research indicates that there are significant benefits of QL instruction for community college students in terms of pass rates and completion times for mathematics requirements, yet how or when students have opportunities to draw on QL in subsequent academic experiences remains under-researched. In particular, we have little information as to how students and instructors perceive the quantitative literacy demands of general education science courses.

Statement of Purpose and Research Questions

The purpose of this multicase study was to explore with six community college students, and their science instructors, perceptions of the QL-demands of general education science courses and the ways in which non-STEM majors connect quantitative ideas across mathematics and science. I anticipate that this research will give us a better understanding of the QL components with which students engage in their science courses, the extent to which students make connections between a QL course and a subsequent science course, and the ways that science instructors perceive the extent to which QL is needed for learning science. It is anticipated that the findings of this research will help inform the process of developing and implementing QL courses in community colleges, and foster thoughtful consideration of the role that science instructors play in advancing students' quantitative literacy. To shed light on these issues, the following research questions are addressed:

1. Which mathematical/statistical components of a specific QL course (Quantway) do students report in tasks from subsequent general education science courses?
2. Which mathematical/statistical components of a specific QL course (Quantway) are to be found in instructor descriptions of tasks in general education science courses?
3. What levels of QL-demand characterize student descriptions of tasks in subsequent general education science courses?
4. What levels of QL-demand characterize instructor descriptions of tasks in general education science courses?

Research Approach

With the approval of the University's institutional review board, I studied the experiences of six community college students enrolled in general education science courses. These participants had all previously completed the same QL pathway that fulfilled both their developmental and college-level mathematics requirements. This investigation employed a multicase study using qualitative research methods.

In-depth interviews were the primary method of data collection. The interview process began with the researcher conducting three pilot interviews, which influenced the final interview protocol used in the main study. Students were interviewed three times over the course of the semester–twice individually, and once in a focus group. Each student's respective science instructor was interviewed once. The information obtained through a total of 18 interviews formed the basis for the overall findings of this study. Each interviewee was identified by a pseudonym, and all interviews were digitally recorded and transcribed.

This study employed methods suggested by Lincoln and Guba (1986) for establishing validity and reliability in qualitative research. First, the study methods were designed to establish credibility—which means working to establish confidence in the truth of the findings. In this study, various methods were employed, including the use of multiple sources of data, member checking, negative case analysis, pattern matching, and the use of secondary coders.

Second, this study frames issues of external validity in terms of *transferability*—by showing that the findings have applicability in other contexts. In this study, thick description of the research context is the primary method of establishing transferability, but the researcher also used replication logic by selecting cases for both *literal* and *theoretical* replication.

Third, this study frames the issue of reliability in terms of *dependability* and *confirmability*. Dependability refers to the extent that research is conducted in a consistent manner that can be repeated (Lincoln & Guba, 1986). To help establish dependability, the same data collection procedures were employed for each case, including consistent protocols and a consistent set of initial questions for each interview. Confirmability refers to the extent that the study respondents, not researcher bias, shape the findings (Glesne, 2011). To help establish credibility in this study, multiple data sources were involved, attention was paid to reflexivity (by documenting researcher biases), and outside investigators were recruited to independently code sections of transcripts. Employing an outside person in this manner is one way for qualitative researchers to enhance the credibility of their methods (Riege, 2003).

Assumptions

Based on the researcher's background and experiences with QL curriculum and instruction, as well as teaching in community colleges, four primary assumptions were made regarding this study. First, that more research is needed on alternatives to traditional developmental mathematics courses, because those courses are not serving the needs of the majority of community college students who take them. This assumption is based on the premise that the percent of community college students who pass traditional developmental courses is very low–as low as 10% for certain demographics. Although alternative pathways, such as QL courses are gaining popularity in community colleges, the field suffers from a lack of information about student experiences with these alternatives. Second, that there are a variety of reasons for teaching mathematics courses to non-STEM majors, including preparation for subsequent academic courses. This assumption is guided by the notion that although many non-STEM majors who take developmental mathematics courses never take more than two college-level mathematics courses, they do take other courses with significant quantitative demands. Third, that the percent of students who pass a course is not, by itself, a sufficient measure of success when it comes to assessing the effectiveness of a course. This assumption is based on the belief that one goal of mathematics instruction is for students to understand the material being taught, not just pass courses. Related to this assumption is the idea that it is a good thing when students can see connections between mathematics and other college courses. A fourth assumption is that community college students who complete their developmental mathematics requirements are motivated to succeed in other college-level coursework. This assumption is based on the premise that the students who invest the time, energy, and financial resources necessary to pass remedial courses will be willing to invest just as much in courses, such as subsequent science courses, that count toward their degrees.

The Researcher

In qualitative research, the researcher is the primary instrument of data collection (Creswell, 2013). My contribution to the research is not necessarily a negative limitation, but my interpretations of constructs such as quantitative literacy and my experiences with community college students and instructors did influence how I perceived the research. I therefore take seriously the process of documenting and clearly articulating my own perceptions and biases.

I began my own post-secondary education as a community college student (1999–2001), and have served several semesters as a community college mathematics instructor (2010–2012; 2015). I believe that my knowledge of the research context enhances my awareness of, and sensitivity to the complex challenges faced by my research participants. I also bring certain biases to the research. Although every reasonable effort was made to ensure objectivity, these biases presumably shaped the way I interpreted the data. For example, I began this study with the perspective that mathematics and science instruction for non-STEM majors in community colleges suffers from a lack of consistent approach across courses, and more effective collaboration between mathematics and science instructors would be largely positive for students. I heard many first-hand accounts from students who were required to take mathematics courses that they perceived had no connection with courses in their major, or other general education requirements. As a former community college instructor, I am aware that the content of my Intermediate Algebra, and College Algebra courses was not altogether in line with the kinds of quantitative skills students needed in subsequent coursework.

In addition, my curriculum work at Michigan State University includes the design and implementation of quantitative literacy courses. This experience shaped my own views on the importance of QL, and also made me more attuned to the challenges of implementing QL curriculum. Even my own mental conceptions of QL are better aligned with the Quantway curriculum than with other, no less valid, conceptions of QL such as mathematics for social justice. Tracing when and how my own biases appeared throughout this study was an important step toward self-monitoring.

Rationale and Significance

The rationale for this study stems from my desire to gain a better understanding of the academic experiences of community college students, particularly after they complete their general mathematics requirements. Community college students may be traditional full-time students, part-time students, working parents, or people who are returning to college after many years away from the classroom. Many of my own students had negative experiences with mathematics in the past, and failed to see its usefulness outside the mathematics classroom. QL instruction seems to offer many benefits to these students, but the benefits are often advertised in such a way as to make mathematics seem like an obstacle to be overcome, as opposed to a useful lens for understanding the world.

Increased understanding of the experiences of QL students in subsequent science courses not only has the potential to inform the design and implementation of QL courses, but could also shed light on the conditions under which students' make use of QL in other academic contexts. Improving QL instruction, based on research-grounded evidence, may afford more students with opportunities for academic success, improve their learning in subsequent courses, and improve their personal gratification at learning a new subject. Such understanding may also benefit our society at large.

Definitions of Key Terminology

Community college students: This term is used to refer to students who are enrolled *solely* in a 2-year post-secondary institution (formerly called *junior colleges*–see Medsker, 1960). They are considered a student whether or not they are pursuing a 2-year degree, certificate, or intend to transfer to a four-year institution.

Developmental mathematics: Consistent with other research on community college mathematics education (e.g. Blair, 2006), I use this term to refer to any mathematics course which a student must complete *before* they are allowed to enroll in credit-bearing mathematics coursework. Other terms for such courses include remedial, foundational, or pre-college courses.

General education science courses: Occasionally shorted to *general science courses*, I use this term to refer to courses that fulfill the core curricular requirements that exist for all students regardless of major. Broadly, these include 100- and 200- level courses connected to both the physical and biological sciences. This term does not include courses directed primarily at science majors such as physics or organic chemistry.

Mathematical/statistical components: In this study, I largely use the term *components* to refer to broad categories such as basic numeracy, data analysis, or geometric reasoning. Each component is associated with more specific techniques such as 'the ability to estimate an answer before performing a calculation'. I also use this term to differentiate such components from affective components such as attitudes toward, or beliefs about, mathematics.

Quantway: A two-semester undergraduate mathematics pathway geared toward improving students' quantitative literacy. When I use this term without any modifiers, I refer to the Quantway course in which a student can enroll. Students whose placement scores put them in the lowest level of developmental mathematics may choose to take Quantway. If they pass both semesters, they receive credit for one college-level mathematics course.

Quantway students: Students who take *Quantway* as part of their undergraduate coursework.

Quantway curriculum: The written documents that comprise the daily lessons for Quantway. In this dissertation, I primarily drew on the instructor's manual, provided by the Carnegie Foundation for the Advancement of Teaching.

Task: Used with modifiers such as *science,* or *quantitative literacy*, this term refers to a unit of classroom activity, the purpose of which is to focus students' attention on a particular idea (Stein, Grover, & Henningsen, 1996). A task includes the products students are expected to produce, the operations students use to generate those products, and the resources available to the student while they are generating the product (Doyle, 1988). A single classroom lesson may incorporate multiple tasks, each characterized by the particular idea on which each task is focused.

Task-description: The verbal description of a task provided by a participant (either a student or an instructor).

CHAPTER II: LITERATURE REVIEW

Overview and Organization

The purpose of this study was to explore with a group of community college students, and their science instructors, the quantitative literacy demands of general education science courses, and the ways in which students connect quantitative ideas across courses. I sought to understand ways in which the quantitative experiences of students in a specific QL course (Quantway; Carnegie Foundation for the Advancement of Teaching, 2012) related to the quantitative experiences of these same students in subsequent general science courses, by concentrating on connections students and instructors reported between those two educational experiences. To carry out this study, it was necessary to conduct a critical review of relevant literature. This review was ongoing during throughout the data collection, analysis, and synthesis phases of the study.

This critical review explores the interconnectedness of multiple bases of literature, including quantitative literacy, the quantitative demands of general education science courses, and ways in which students connect concepts between mathematics and science courses. The literature basis for each of those areas is vast, so it was necessary to narrow my focus to research and literature that is pertinent to ongoing work in community college mathematics education, and that has informed the conceptual framework used for analyzing study data. In light of this, I chose to include in this review three major areas of literature: (a) Quantitative literacy, with a specific focus on how QL is operationalized through the Quantway curriculum, (b) Research reports of the quantitative demands of general science courses, with a focus on potential overlap with the Quantway curriculum, and (c) Research and literature on factors that influence student connection-making across mathematics and science courses.

Reviewing literature on QL, as it is operationalized in Quantway, provides information on a mathematical experience shared by the student participants, and suggests certain QL components that these students might be able to recognize in their subsequent science courses. The section on the quantitative demands of general education science courses provides a complementary angle on hypothesizing which aspects of Quantway might appear in such courses, and provides insight into instructor reports. Literature on the ways in which students connect mathematics and science instruction provides a tentative theoretical lens through which we might make sense of student reports.

Those readers wishing to know the conclusion before reading the literature review will find that that the overall picture features several key points: (1) The mathematical/statistical components of the Quantway curriculum can be characterized in terms of a several broad categories, including basic numeracy, algebraic reasoning, data analysis and representation, spatial reasoning, and mathematical modeling. The Quantway program is intended to help students acquire the quantitative literacy skills needed in everyday life and for academic success. (2) The quantitative demands of a general education science course can be characterized in terms of similar mathematical/statistical components, but framing quantitative demands in terms of different levels of quantitative thinking provides a rich complementary dimension. Both dimensions will be important for analyzing study data. (3) Whenever students are asked to report connections between two academic courses, we run into issues of transfer – a complex cognitive phenomenon. One way to make sense of student reports is to classify them in terms of spontaneous connections, prompted connections, no connections, or incorrect connections. All of these assertions are based on the overall judgments I have formed from the following analysis of literature.

To conduct this selective review, I drew upon several sources of information, including books, dissertations, policy reports, professional journals, and conference presentations. I primarily accessed these sources through Jstor, ProQuest, ERIC, and Google Scholar. No specific fixed time frame was used to delimit my search. Because of the nature of the literature reviewed, including historical perspectives on the place of QL in mathematics in science education, I felt that an arbitrary time frame might inhibit the inclusion of notable material.

Throughout this review, I attempt to point out important gaps in particular components of the literature when they become apparent. I also highlight a few contested issues and provide alternate interpretations. I close each section of this review by synthesizing the pertinent information, and focusing on the research implications for this present study. The chapter concludes with an interpretive summary that demonstrates how the literature led to the formation of the conceptual framework used in both data collection and analysis.

QL and the Quantway Program

The concept of quantitative literacy did not originate in the United States, and its usage in mathematics education can be traced to British educators who used the term *numeracy* as early as the 1950s (Department of Education and Science, 1959). An influential report on mathematics in British schools, *Mathematics Counts* (Cockcroft, 1982), suggested that schools place more emphasis on teaching numeracy–the ability to understand quantitative information, and (notably for our study) to use mathematical skills in everyday situations. These situations included the kinds encountered during the course of one's normal day, at the workplace, and in further academic courses and training.

Steen (1990) suggested that quantitative literacy consists of several elements, including *Practical, Civic, Professional, Leisure,* and *Cultural* numeracy. These are the skills and habits of mind necessary to navigate situations as diverse as estimating unit prices, understanding public policy debates, comparing interest rates and terms on loans, and appreciating the role of mathematics in one's culture. Furthermore, Steen (2001) argued that although QL possesses no inherent content of its own, it is always to be found rooted in the real data that humans experience as part of life's manifold contexts and situations.

This present study specifically deals with QL as it appears in selected community college courses. Therefore, it is important to consider how QL came to become part of community college mathematics instruction. Consistent with reform documents at the K-12 level (e.g. *Principles and Standards for School Mathematics*, National Council of Teachers of Mathematics, 2000), the American Mathematical Association of Two-Year Colleges (AMATYC) released *Crossroads in Mathematics* (Cohen, 1995), and *Beyond Crossroads* (Blair, 2006) to conceptualize the two-year college position on reforming mathematics curriculum and instruction. The authors of the *Crossroads* documents encouraged community colleges to incorporate more QL in mathematics instruction, and to consider using QL as the basis for mathematics courses for non-STEM majors (Blair, 2006).

The American Mathematical Association also published a policy report with respect to the first two years of collegiate mathematics instruction that has been influential in many community college mathematics departments. College Renewal Across the First Two Years (CRAFTY) (Ganter & Barker, 2004) called for increased emphasis on improving students' quantitative reasoning abilities, which the authors defined as (1) the ability to use and interpret mathematics in real-life situations; (2) the ability to interpret statistics and other forms of data; and (3) fluency with the computational skills that are useful in the workforce.

Does one’s everyday life actually require the use of mathematical or statistical thinking? Several reports indicate that quantitative skills are necessary for success in diverse areas of life, including managing one's personal health (Apter et al. 2009; Brown et al. 2011; Schwartz, Woloshin, Black, & Welch, 1997), understanding the informed consent process (Couper & Singer 2009), access to opportunities for employment (Charette & Meng 1998; Kirsch, Leathers, & Snead, 1993) and for making good financial decisions (Gerardi, Goette, & Meier, 2013).

Steen (2004) and others have emphasized that QL is more than just a list of specific mathematical or statistical techniques, and that it includes behavioral and dispositional elements. This is important for the present study because the students were being asked to reason with mathematics in new contexts. As Steen (2004) puts it [italics added]:

> Personal success in the new information economy requires a new set of problem solving and behavioral skills that emphasize the *flexible appreciation of reasoning abilities*. These skills involve sophisticated reasoning with elementary mathematics, more often than elementary reasoning with sophisticated mathematics (p. 9).

From the research and literature highlighted above, it appears that QL involves at least two dimensions: Specific mathematical and statistical tools needed to make sense of real-life experiences, and the dispositional (e.g. behavioral, motivational) tendencies to reason critically using mathematics. Furthermore, the fact that Steen views QL as involving a “flexible appreciation of reasoning abilities” indicates that one goal of QL instruction ought to be developing the capacity to recognize when and where such reasoning abilities are needed. Moving from ideals to actual curriculum is no small challenge, which leads us to consider one way in which QL is currently operationalized in many community colleges.

Background

In response to calls for action from AMATYC and the MAA, many groups connected with community colleges developed quantitative literacy courses, which were often intended as alternatives to the normative mathematics sequence of intermediate and college algebra (Cullinane and Treisman, 2010). Many of those efforts were intended to help community college students who had placed into developmental coursework. Examples include the AMATYC *New Life* program (Rotman, 2013), and the *New Mathways Project* (Charles A. Dana Center, 2014). The largest effort, in terms of current student enrollment, to implement QL courses in community colleges is *Quantway*, a creation of the Carnegie Foundation for the Advancement of Teaching.

Quantway is a two-semester pathway for students who place into developmental mathematics that leads to credit for a college-level mathematics course. The program is a sequence of two quantitative literacy courses meant to replace Intermediate and College Algebra for students who do not intend to pursue STEM majors. The goal of the courses is primarily to improve students' quantitative reasoning abilities so that they might use and apply mathematics in their daily lives, and be prepared for future academic study. The written curriculum is centered on several mathematical and statistical categories (such as *statistics and data analysis*), and each of these categories is further defined by specific learning goals such as *distinguishing between statements involving absolute and relative change*. The Quantway curriculum includes a system of inquiry-based learning activities, and uses heavily contextualized problems[1].

To date, forty-nine community colleges in fourteen states offer the Quantway course sequence to approximately 10,000 students (Carnegie Foundation for the Advancement of

[1] A limited overview of the Quantway program, may be found at: http://www.carnegiefoundation.org/in-action/carnegie-math-pathways/

Teaching, accessed 2016). Support materials for instructors include specific routines faculty are to follow to improve the quality of group-work, and implement the Quantway instructional approach in their classrooms (Howington, Hartfield, & Hillyard, 2015). Each community college is responsible for determining whether or not the courses can count for college mathematics credit, and for which other courses Quantway is allowed to serve as a prerequisite.

Some of the most persistent problems surrounding developmental mathematics courses involve withholding instruction of complex and interesting material until students have mastered easier material (Hiebert et al., 1996). Such practices may be fostered by widely-held beliefs among students and teachers (Mtetwa & Garofalo, 1989; Felbrich, Müller, and Blömeke, 2008) that (a) mathematics is a set of rules that require memorization, (b) problems are always solved by using formulas, and (c) problems always have one correct answer. The Quantway program represents an attempt to bring complex mathematical problems into developmental mathematics classrooms.

One way to characterize the Quantway curriculum is through the types of mathematical and statistical content featured throughout the written curriculum. I grouped this content in five areas: basic numeracy, algebraic reasoning, statistics and data analysis, spatial/geometric reasoning, and mathematical modeling. I further visualized the Quantway curriculum may be thought of as a sequence of reality-related tasks (Maaß, 2006) in which students learn to use mathematical and statistical tools in the context of realistic situations. Let us briefly consider a few examples of these tasks, with an eye toward how the Quantway curriculum helps delineate the mathematical/statistical components of QL for the conceptual framework used in this study.

Basic Numeracy

Basic numeracy has a variety of meanings within literature on QL (Karaali, Villafane Hernandez, & Taylor, 2016), where it is occasionally used as a synonym for QL, and occasionally used as an aspect of QL. Vacher (2014) notes that numeracy is associated with numbers, whereas QL in a larger sense incorporates many non-numerical aspects of logic and mathematical or statistical reasoning. In the Quantway curriculum, there are several learning objectives related to basic numeracy, all of which give us a picture of how this construct is operationalized in the curriculum: These include performing arithmetical calculation, estimating an answer before performing calculations, using and interpreting scientific notation, using and interpreting percentages, checking the reasonableness of one's answers, displaying measurement sense (e.g. in terms of units), and understanding absolute versus relative change.

Figure 1 represents a portion of a Quantway lesson centered on basic numeracy. These examples, and all subsequent images from the Quantway curriculum, are copyright 2015 by the Carnegie Foundation for the Advancement of Teaching and should not be reproduced. It is important to note that this dissertation is not an analysis of the Quantway curriculum. Indeed, one should refrain from drawing too many conclusions from written Quantway materials, due to the significant role instructors and support materials play during actual classroom implementation.

Table 1.

Quantway Lesson 1.3

A law enforcement officer reviews the following data from two precincts. She makes a quick estimate to answer the following question: "If a violent incident occurs, in which precinct is it more likely to involve a weapon?" Make an estimate to answer this question and explain your strategy.

Precinct	Number of Violent Incidents	Number of Violent Incidents Involving a Weapon
1	25	5
2	122	18

Following the scenario are a series of questions that involve estimation, converting fractions to decimals, and making sense of percents.

Algebraic Reasoning

The notion of algebraic reasoning extends beyond the content of the typical Algebra courses taught in many U.S. middle and high schools. It includes reasoning about formal, rule-governed structures, and the manipulation of mathematical expressions (Smith and Thompson, 2007). In Quantway, lessons centered on algebraic reasoning also include reasoning more generally about covariation. Specific learning objectives from Quantway that are considered aspects of algebraic reasoning include understanding the role of variables, describing the effect of changing one variable in an algebraic relationship, constructing and using equations in one or more variables, as well as applying algebraic relationships to solve real-life problems.

A problem situation in the Quantway curriculum that centers on algebraic reasoning is shown in the quote below (Quantway lesson 4.3):

PROBLEM SITUATION: MILK AND SOFT DRINK CONSUMPTION

Over the last 60 years, the U.S. consumption per person of milk and soft drinks has changed drastically. For example, in 1950, the number of gallons of milk consumed per person was 36.4 gallons; in 2000 that number had decreased to 22.6 gallons. Meanwhile, the number of gallons of soft drinks consumed per person in 1950 was 10.8 gallons. By 2000, this number increased to 49.3 gallons per person.[1]

In the following questions, you will find out when the consumption per person of milk equaled (or will equal) the consumption per person of soft drinks. For this problem, we will build linear models for milk and soft drink consumption. Assume that the change in consumption is linear.

Follow the problem situation, students are asked to create linear equations representing soda and milk consumption versus time, re-arrange the equations to solve for specific variables, and find the point of intersection of the two lines by algebraic manipulation.

Statistics and Data Analysis

Several scholars have noted the place of statistics in operationalizing QL, including Mayes, Peterson, and Bonilla (2013) and Steen (2001). The Cockcroft report (1982, p. 236) included “a commonsense approach to the use of data…and a judicious understanding of widely used concepts such as means and percentages” in a list of characteristics of statistical numeracy. In Quantway, there are several learning objectives related to statistics and data analysis. These include: Computing basic statistics (measures of center and spread), evaluating statistics that appear in the media, describing correlation and causation, reading and making decisions based on visual displays of data, evaluating the sampling strategy used in a study, determining sources of bias in a media report, and using the language of probability to evaluate statements regarding risk. A portion of a Quantway lesson that emphasizes statistics and data analysis is shown in the quote from lesson 6.8, and Figure 1:

Problem Situation: Another Look at Homelessness

Policy makers, like state senators or legislators, make decisions about how to spend money on social services. Social services can include housing for homeless people. To make decisions about allocating resources, policy makers often use data in charts and graphs. These graphs help them decide what services should get money and how much.

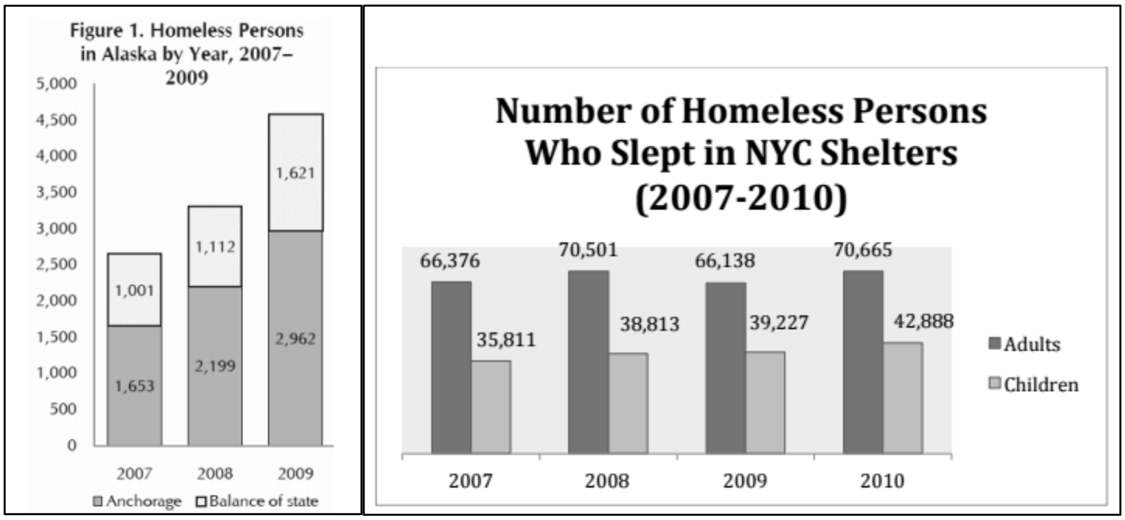


Figure 1. Quantway Lesson 6.8 (used with permission)

In this lesson, students are asked to derive meaning from different types of graphical representations, and eventually construct their own graphs based on two-way tables. Although the Quantway curriculum, and in particular the support materials for instructors, considers probability and statistics as one set of learning goals, the conceptual framework I selected for this study separates these constructs. This decision was based, in part, on literature surrounding QL and science, so I will explain this decision in an upcoming section.

Geometric Reasoning

Geometry occupies an interesting position both within Quantway, and within larger discussions on QL. Karaali et al., (2016) note that geometry frequently appears in textbooks and other documents in which the focus is on helping students develop an appreciation for mathematics, but that geometric thinking has limited popularity in discussions on QL. These authors note that spatial reasoning is a skill used in many professions including engineering and architecture, but that the role of spatial reasoning in the everyday lives of most people is limited. Wiggins (2003) includes aspects of spatial reasoning in his discussion of QL, including the geometry of transformations and the use of simple formulas for finding areas, perimeters, or volumes of shapes.

Geometric reasoning occupies the smallest portion, in terms of sheer number of daily lessons, in the Quantway curriculum (with Basic Numeracy representing the largest). Lessons involving geometric reasoning include estimating cost per acre of property, or drawing a scale model of a township. Other lessons combine geometric reasoning with one or more additional categories, such as creating a pie chart (i.e. determining areas of circle sectors) based on survey data. In fact, there are only three learning goals in the instructor's manual for Quantway that are connected with geometric reasoning: (1) Solving geometric problems involving area, perimeter, or volume (2) Translating between different units of measurement and (3) Solving problems involving scaling.

A portion of a Quantway lesson involving geometric reasoning is shown in the following quote from Quantway lesson 3.4 and Figure 2. In this lesson, students calculate the areas of different suburban lots, and use these areas to compute the cost of fertilization.

PROBLEM SITUATION: HOME IMPROVEMENTS

Bob and Carol Mazursky have purchased a house and the small piece of land that surrounds the house. (A small piece of land that can be purchased or sold is often called a **lot**.) Bob and Carol want to make some improvements to their new property. In the following few problems, you will calculate the costs of these improvements. On pages 7 and 8, you will find scale drawings of the house and the lot. You will need these drawings to calculate improvement costs.

Fenced-in Backyard: The light shaded area to the rear of the house represents the backyard that is to be fenced in and reseeded. The fence is to enclose the entire area, except for the area adjacent to the house. Each corner requires a "corner post" and each gate requires two corner posts. The gates are adjacent to the house. Regular posts need to be set along each side and should be no more than eight feet apart.

Figure 2

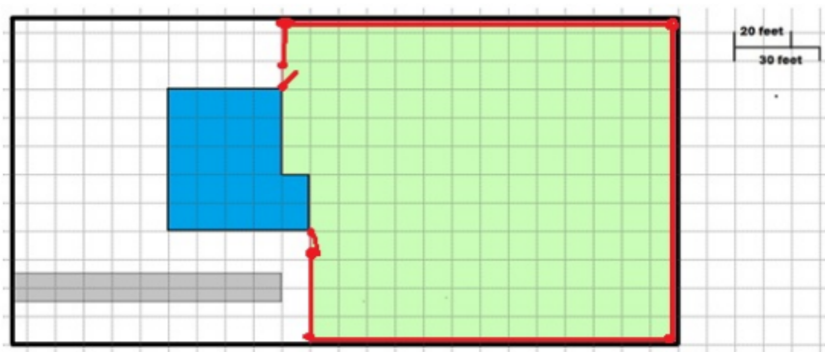


Figure 2. Quantway Lesson 3.4 (used with permission)

Mathematical Modeling

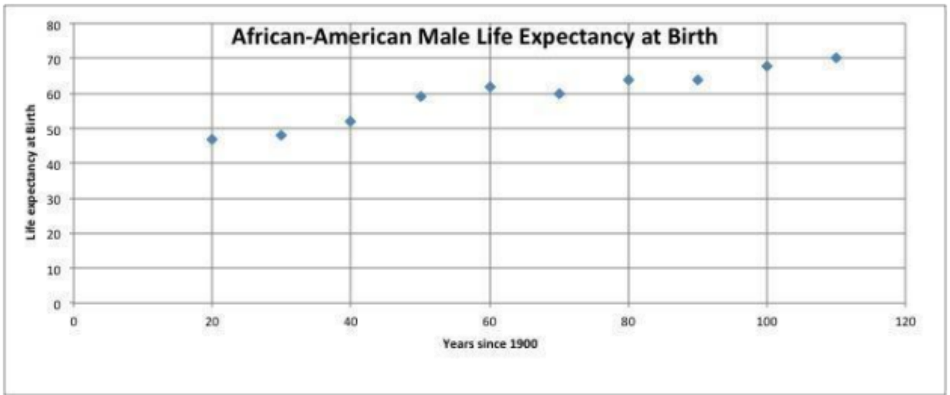
Modeling with mathematics features prominently throughout the Quantway curriculum. For example, one of the learning goals intended to improve students' algebraic reasoning is that students will model a real-life scenario using an equation in one or more variables. Other learning objectives include: Create models of contextual situations in one or more variables, recognize that all mathematical models are subject to error, apply a mathematical model to solve a real-life problem, and develop a linear model to approximate data.

A portion of a Quantway lesson centered on mathematical modeling is shown in the quote below from Quantway lesson 4.3 and Figure 3. Students are asked to create a linear model given a scatter plot, and use the model to answer various questions.

PROBLEM SITUATION: LIFE EXPECTANCY AND SOCIAL SECURITY

As you read in the PNL, one proposal to reform Social Security is to increase the retirement age. This, however, raises concerns about fairness. No matter what the retirement age is, some people will pay into Social Security but die before retirement and never receive a benefit. This happens to more people when the retirement age is increased. In this lesson, you will examine the effects of raising the retirement age to 75. Specifically, you will answer the question of whether this change would have a greater impact on some groups than others.

To explore this question, you will use life expectancy data from the Centers for Disease Control. Real data rarely fall on a straight line, but sometimes data show a definite trend. If the trend is close to linear, the data can be *approximated by a linear model.* This means that a linear model gives good estimates of what the data will be if the trend continues. A model can also be used to estimate values between data points. In this lesson, you will learn to create linear models from data.



Working with your instructor, find a linear model to approximate these data, letting L be the life expectancy at birth and y the year of birth measured in years after 1900.

Figure 3. Quantway Lesson 4.3 (used with permission)

Mathematical modeling is found throughout Quantway both as the focus of entire units, and also within a spectrum of other lessons. This reflects the notion that it is difficult to separate modeling from quantitative literacy. Indeed, Kaput (1988, p. 16) claimed, “Quantitative reasoning…can be regarded as modeling”. Although this perspective has some merits, it forces us to consider how mathematical modeling fits within the conceptual framework for this study.

The conceptual framework used in this study draws on aspects of QL that appear in the Quantway curriculum, but it also takes into account how and when aspects of QL might appear in general education science courses. Considering QL in light of science courses led me to make certain decisions with respect to categorizing the mathematical/statistical components of Quantway. I now present the science literature that informed many of those decisions.

QL and General Education Science Courses

In the previous section, we considered quantitative literacy from a primarily mathematical perspective, and cited authors who primarily work in the field of mathematics education. These authors described QL in terms of using mathematics in everyday life-situations such as personal finance, or being an informed democratic citizen. The Quantway curriculum represents a very mathematical conception of QL, and we have seen that one of its major purposes is to help students reason with mathematics outside the classroom. At the same time, one of the goals of Quantway is to prepare students for further academic study, and it is this goal that originally motivated the present research. One of the areas of further academic study that many Quantway students encounter in community colleges is the study of science.

There is a growing cognizance that many students who take undergraduate science courses are unprepared for the quantitative demands of those courses (Ganter & Haver, 2011; Speth et al., 2010). Most research on this phenomenon has centered on the plight of students majoring in scientific fields such as physics, pre-engineering, or pre-med (e.g. Bassok & Holyoak, 1989; Frith & Gunston, 2011; Rheinlander & Wallace, 2011;). Less represented in the existing literature is a body of work on the quantitative demands of science courses taken by the general population of non-STEM majors. Nevertheless, there is a sufficient research base on general education science courses that has been instrumental in shaping the conceptual framework for this study.

Mathematics, Statistics, and Science Courses

A majority of the nation's undergraduates are required to complete general science courses (Follette, McCarthy, Dokter, Buxner, & Prather, 2015), which include survey courses in both the physical and life sciences. There is some evidence that quantitative literacy and science literacy represents a reflexive relationship. For example, Shamos (1995) argued that without understanding the role of mathematical reasoning in science, a person could never fully appreciate the scope of scientific discovery. Alternately, several studies (Hathcoat, Sundre, & Johnson, 2015; Hester, Buxner, Elfring, & Nagy, 2014; Powell & Leveson, 2004; Speth et al., 2010) indicate that general education science courses have the potential to improve students' numerical skills.

Educators have long considered the role of mathematics in general science instruction (see Dewey, 1909; Miller, 1983; Rutherford & Ahlgren, 1991; Shamos, 1995). Indeed, Miller (1983, 2010) has argued for over thirty years that quantitative reasoning is necessary to make rational decisions about scientific problems. He cites a variety of scientific issues that face the average citizen, and which require a non-trivial amount of quantitative reasoning. These issues ranged from the fluoridation of drinking water, to the use of genetically modified foods, to carbon emissions caps on industry, to containing the spread of disease. Miller (2010) estimated that only 28 percent of American adults have enough knowledge of science to make sense of the Science section of the New York Times, and one reason for this low incidence of scientific literacy is the relatively low percent of adults who can read and interpret numerical information.

Mayes, Peterson, and Bonilla (2013) suggested that science literacy includes the ability to think in terms of both macro and micro scales. For example, a scientifically literate person should be able to consider environmental issues at both the molecular scale (what exactly *is* carbon dioxide?), and the global scale (what effect does climate change have on island nations?). Viewing scientific phenomena at both scales involves skills such as estimation, pattern recognition, modeling future events, measurement, number sense, proportional reasoning, and basic knowledge of statistics and probability.

What does a desire to increase levels of science literacy in the general population mean for college science courses? Trefil and Hazen (2010) note that many science courses, particularly those aimed at the general population of undergraduates, cover a broad range of scientific ideas without getting looking deeply at any particular topic . A greater focus is placed on giving students sufficient knowledge of the physical universe to deal with science issues that affect our daily lives, and also to develop a desire to further study science.

Creating a science curriculum that will prepare students to deal with scientific issues throughout their lives seems to require some prophetic abilities. As Miller (2010) asserts, it is somewhat challenging to prepare students to deal with future scientific ideas when we don't know what ideas will arise over the next few decades. Few of today's citizens learned about the human genome project in school—it didn't exist—yet genetics is a major theme in today's scientific discussions and even appears in elementary school science standards (NGSS, 2013). Many first-year undergraduate science courses, particularly those aimed at non-science majors, appear to deliver a blend of training in disciplinary-specific techniques, and scientific reasoning skills. Table 2 summarizes previous research on the quantitative components that play a role in a selection of such courses.

Table 2.

Quantitative components of first-year college science courses

Study	Discipline	Quantitative Components
Downs & Liben (1991)	Geosciences	Understanding different map projections Scaling
Dyche et al. (1993)	Astronomy	Units of measurement (astronomical distances)
Chang (1999)	Geosciences	Spatial reasoning (kinetic-molecular theory)
Lake (1999)	Life Sciences	Data analysis and representation Fitting a line to a scatter plot
Phoenix (1999)	Life Sciences	Performing and simplifying arithmetic calculations Mentally estimating answers Checking to see if an answer is within reasonable bounds Manipulating algebraic expressions Using exponents and logarithms Scientific notation
Slater & Adams (2002)	Astronomy	Basic arithmetic Comparing graphical representations Logical reasoning Algebraic manipulation
Black (2005)	Earth Sciences	Interpreting visual representations of data Scientific notation and geologic time Scale models Spatial reasoning
Schapira et al. (2008)	Health sciences	Basic arithmetic Interpreting graphs Probability and chance Understanding uncertainty Variation in outcomes Estimation
Speth et al. (2010)	Biology	Basic arithmetic (averages, percentages, frequencies, and proportions) Representing data Interpret simple statistics (error bars and trendlines) Experimental design Hypothesis testing

It is worth noting that several of the authors listed in Table 2 note that the students who take undergraduate science courses frequently suffer from a weak foundation in quantitative reasoning. Rheinlander and Wallace (2011) report that the ability to model change is a common theme across all biological sciences, but that many students are not prepared for either creating or interpreting even linear models. Black (2005) and Chang (1999) separately report common earth science misconceptions (e.g. that the earth's shadow causes the phases of the moon) that are due to weak spatial reasoning skills.

In terms of this study, the value of understanding this body of literature lies in forming conjectures about the mathematical/statistical elements of Quantway that might appear in participants' general education science courses. In summarizing the literature above, we can see that there are multiple elements of QL related to science, including (1) the ability to carefully measure and comprehend quantities, (2) basic number sense including orders of magnitude and the ability to interpret both large and small numbers, (3) algebraic and proportional reasoning, (4) descriptive statistics, (5) familiarity with the language of uncertainty and the ability to reason about chance, (6) the ability to estimate those things which cannot easily be easily measured, and (7) understanding how the geometry of shapes and scaling influences natural processes and phenomena. Such knowledge acts as a window into general science classes, and served as a formative component of the conceptual framework used throughout this study.

Earlier, I noted that listing specific mathematical/statistical components is only one way to consider quantitative literacy or, for that matter, the quantitative demands of science courses. Steen's (2004) suggestion that QL includes an appreciation of flexible reasoning abilities leads us to consider an entirely different dimension to QL, namely, levels of QL-demand.

Levels of QL Demand

It has been said that many academic courses, ranging from the humanities to law (Frith, et al., 2010) place significant quantitative literacy demands on learners. Disciplines such as Engineering make complex demands, not just in terms of mathematics, but also QL (Rheinlander & Wallace, 2011). Whereas the mathematical elements of certain science courses (i.e. physics for engineers) are well understood, the quantitative literacy demands of many academic courses are often un-stated, or not explicitly recognized (Macdonald & Bailey, 2000). The previous section summarized research into the mathematical/statistical components related to QL that have been reported in a variety of science courses. Yet defining the QL demand of a course simply as a list of mathematical topics only tells part of the story.

How else might we characterize the QL demands of academic courses? Frith and Prince (2009) created a taxonomy (Figure 9) by which any academic task might be analyzed in terms of the kinds of thinking and reasoning it requires. The authors define a quantitative literacy *event* as any classroom task, homework assignment, laboratory experience, or classroom discussion involving quantitative reasoning. Each event carries with it opportunities for students to think and reason quantitatively, regardless of the actual mathematical tools required by the task. Frith and Prince (2009) describe six levels of quantitative literacy demand that may exist within an academic task: *Knowing, Identifying and Distinguishing, Deriving Meaning, Applying Mathematical Techniques,* and *Expressing Quantitative Concepts*.

To date, very little research exists on identifying the levels of quantitative literacy demand in courses across the general undergraduate curriculum. Instructors often equate quantitative literacy demands with doing calculations, and therefore fail to recognize the substantial cognitive requirements certain tasks place on students with respect to QL (Frith &

Prince, 2009). Specifying the various demands that different tasks place on students' cognitive processes is important in the larger context of this study. For example, Mesa (2012) notes that many community college instructors, in the absence of data, are forced to make assumptions about the kinds of reasoning that classroom tasks will require. Finding ways to be explicit about the QL demands of tasks can only help this situation.

Frith and Prince (2009) acknowledge that many levels can exist simultaneously within the same quantitative literacy event. Nevertheless, as I began this study, I conjectured that there are fewer opportunities for students to engage in *higher order thinking* and *expressing quantitative concepts* within a general science course, than there are for lower levels such as *knowing*, or *identifying and distinguishing*. Furthermore, tasks that involve *higher order thinking* are important for this study, because Quantway claims to prepare students to synthesize information, reason logically, make and interpret conjectures, and evaluate the adequacy of solutions. Such actions relate to the idea of becoming "critically aware" (Johnston, 2007, p. 53).

It is not at all certain that community college students have opportunities to engage in higher order thinking in general education science courses, or if there is any relationship between the kinds of reasoning practiced in tasks throughout a QL course, and that which is required by tasks in students' subsequent coursework. Stein, Grover, and Henningsen (1996) note that an important distinction in research on academic tasks is the differences between tasks that engage students at a surface level and those that engage students at deeper levels. The Frith & Prince taxonomy is one lens that researchers can use to see this distinction more clearly.

Table 3.
Levels of QL-demand (Frith & Prince, 2009, p. 89)

1. Knowing	• Knowing the meanings of quantitative terms and phrases (*verbal* representations). • Knowing the conventions for the *symbolic* representation of numbers, measurements, variables and operations • Knowing the conventions for the representation of quantitative information in tables, charts, graphs, diagrams and objects (*visual* representations).
2. Identifying and distinguishing	• Identifying connections and distinction between different representations of quantitative concepts • Identifying the mathematics to be done and strategies to do it • Identifying relevant and irrelevant information in representations.
3. Deriving meaning	• Understanding a verbal description of a quantitative concept/ situation/process • Deriving meaning from representations of data in context • Deriving meaning from graphical representations of relationships • Deriving meaning from diagrammatic representations of spatial entities • Translating between different representations.
4. Applying mathematical techniques	• Using mathematical techniques to solve a problem or clarify understanding -- for example: calculating, estimating, measuring, ordering, modeling, applying algebraic techniques etc.
5. Higher order thinking	• Synthesising information or ideas from more than one source • Logical reasoning • Conjecturing • Interpreting, reflecting and evaluating.
6. Expressing quantitative concepts	• Representing quantitative information using appropriate representational conventions and language • Describing quantitative ideas and relationships using appropriate language.

It is important for the reader to know that the only accounts of the Frith & Prince (2009) taxonomy in published research involve applying the taxonomy to written curriculum documents. While important, the written curriculum only represents one perspective on any academic task. Remillard (2005) notes that teachers are more than conduits who convey curriculum to students, and therefore the written curriculum can differ significantly from the enacted curriculum. Furthermore, Jansen (2011) and others (e.g. Goodlad, 1979) note that students also mediate curriculum, resulting in a received curriculum that may differ based on personal student characteristics. This study will represent a first attempt at applying the Frith and Prince taxonomy of quantitative literacy demand levels to student and instructor descriptions of science tasks.

There remains one final lens that I wish to discuss before moving to a summary and presentation of a conceptual framework. Part of this dissertation research relied on the ability of students or instructors to report connections between tasks in one academic experience (Quantway) and those in another (a subsequent science course). Is it even reasonable to expect them to make and report such connections at all? If so, how might we characterize the ways in which students make such connections?

Bridging Mathematics and Science: How Students Connect Tasks

One of the most persistent results in mathematics education studies is that students who solve problems in one area are often unable to transfer their conceptual or procedural knowledge to solve similar problems in other areas (Bassok & Holyoak, 1989). Such results are disappointing because one goal of mathematics education is to impart knowledge that can be applied to situations other than those in which the material was originally taught. Quantitative literacy is inherently tied to the idea of preparing students to apply quantitative techniques to problems that exist outside the mathematics classroom. Knowing how to provide classroom experiences that equip students to develop general principles for making sense of quantitatively complex situations, without providing instruction in every specific context imaginable, is an important and enduring problem in our field (Lobato & Siebert, 2002).

Why is the problem of knowledge transfer so intractable? The problem certainly does not suffer from lack of attention. As early as 1906, Thorndike discussed the transfer problem, suggesting there is no reason to expect that improving one mental function should improve others closely related to it. Whitehead (1929) noted students' inability to use appropriate mathematics across similar situations, and referred to the phenomena as "fossilized behavior". Vygotsky (1978) argued that many students' knowledge of school mathematics was "inert", because they could not apply it to situations beyond its original context. Lave (1988) sparked a renewed interest in the theoretical underpinnings of knowledge transfer, eventually leading researchers to study how language, social activity, and cultural artifacts mediate transfer (e.g. Greeno, Smith & Moore, 1993; Pea, 1987). Nevertheless, for reasons still shrouded in mystery, even very proficient students do not readily transfer newly acquired skills to new settings (Barnett & Ceci, 2002). Important for both the conceptual framework and methodology of this study, literature on situated cognition (Cobb, 1988; Cobb & Bowers, 1999; Greeno, 1991) indicates that student memory is episodic and inherently tied to the environment in which learning occurs.

In this study, I sought to understand the connections Quantway students make between what they learned from tasks in their QL course, and new tasks in a general education science course. A primary method for generating data (discussed at length in the next chapter) was to give students a task from Quantway and ask them to think of a similar task in their science course. Part of my intent was to take advantage of students' episodic memory. In order to make such connections, the students would need to recognize similar components in different contexts. During the data analysis phase, I realized that student recognition of QL components was mediated by several interesting factors. Furthermore, a student might make a connection between their science course and their QL course in various ways. This led me to amend the conceptual framework to permit categorization of student connections.

Previous transfer studies suggest that there are several ways in which students might describe a connection between two tasks: They might do so spontaneously, with no prompting from the interviewer (or classroom teacher, as the case may be), or they might make a connection only after prompts that hint to the existence of a similarity between two situations (e.g., "this stock market task resembles the racetrack task you already know," Ceci & Ruiz, 1993, p. 177). Gick and Holyoak (1980) and Reed (1974) have noted effectiveness of simply pointing out the *existence* of a connection between two problems when asking students to transfer knowledge across contexts. There is no guarantee, however, that a student will make a connection even with prompting from the researcher. Furthermore, a student might even make an inappropriate connection between two tasks (e.g. stating that two tasks involve proportional reasoning when in fact they do not). There may yet be other types of connections, but these formed the main source of bins into which I categorized student connection-making throughout the later phases of this dissertation.

Overall Summary

This intent of this review of literature was to identify the key constructs that would inform my research, as well as position the current study in terms of existing theoretical and practical frames. I began this review by exploring characteristics of quantitative literacy, especially as it is operationalized in the Quantway curriculum. Although QL is inherently tied to context, the Quantway curriculum includes some broad mathematical/statistical categories including algebraic reasoning, basic numeracy, geometric reasoning, and data analysis.

A major purpose of this present dissertation is to help describe the academic experiences of Quantway students after they complete their QL coursework. One of the natural areas in which we might expect elements of QL to re-surface is in these students' science courses. A brief review of literature on the quantitative aspects of general education science courses revealed a tentative list of QL components that might reasonably appear in the science courses taken by Quantway students. This dissertation will help us understand how both students and science instructors perceive and report such components.

I reviewed a complementary lens through which to analyze QL that goes beyond listing of mathematical or statistics topics. This lens was suggested by the work of Frith & Prince (2009) and others who consider the quantitative literacy demand levels of undergraduate curricula. Their taxonomy has the potential to help both researchers and instructors bring specific attention to the QL-demands of academic tasks. I concluded with a brief review of literature with respect to the ways in which students might make connections (in short, transfer knowledge) across different academic courses.

In the remaining chapters of this dissertation, I explore the ways in which students and instructors perceive the existence of QL in general science courses, and the connections that students make between their QL course and subsequent courses. In order to analyze the study data, I propose the following conceptual framework.

Conceptual Framework

The above review and critique of literature led to the development of a conceptual framework for the design and implementation of this dissertation. The conceptual framework helped to focus and shape the research process, informed methodological decisions, and influenced the data collection instruments I used. The conceptual framework also became a reservoir for the data I collected, providing the basis for various iterations of a coding scheme. Therefore, this framework provides an organizing structure both for reporting this study's findings and for the analysis, interpretation, and synthesis of these findings. As is the case in many qualitative studies, the conceptual framework was essentially a working tool that both guided the analysis of data, and remained flexible enough to adapt to emerging themes during analysis.

Each category of the conceptual framework is directly associated with the study's research questions as outlined in the introduction. The first research question seeks to discover which aspects of a quantitative literacy course *students* would observe within the arena of a subsequent general education science course. The second research question seeks to discover which QL components general science *instructors* identify as existing within their respective courses. A logical starting place from which to categorize responses to these questions is a series of QL components found in the written curriculum for the students' QL course. As stated earlier, there is much more involved with QL than specific mathematical or statistical components, including various affective structures and habits of mind. For the purposes of this study, however, it was necessary to limit my scope to more easily detected constructs. The specific categories listed below are based on the instructors' lesson plans for each day in the two-semester Quantway course.

The reader will note that the framework below represents a slightly different categorization of quantitative components from that which appears in the Quantway curriculum (summarized earlier). For instance, I have split apart *data analysis and representation* and *reasoning about chance and uncertainty* into their own categories. Statistical thinking certainly uses probabilistic descriptions of variability (Brown & Kass, 2009), but the literature cited on first-year science courses indicates that students encounter probability and data analysis in qualitatively different ways. For example, data analysis appears in conjunction with the ability to read and interpret graphical representations, while probabilistic reasoning appears in conjunction with interpreting statements about risk or chance. Furthermore, analysis of student and instructor task-reports suggested that splitting this category into two would allow for a more fine-grained analysis.

The second significant choice I made in arranging the Quantway components was to highlight components of *mathematical modeling* among the major categories, instead of establishing modeling as its own conceptual category. This was done, for three important reasons: The main reason was to facilitate a more straightforward coding process. It was challenging to separate out precisely which Quantway tasks, and which science tasks were representative of modeling and which were not. Modeling and QL are so intertwined that parsing them would not only be an artificial process, but would distract from the larger goals of this dissertation.

The second reason was because in the data analysis phase of this dissertation, it became highly problematic to decide which science tasks included modeling and which did not,. After much discussion with two Quantway instructors and further attempts to code science tasks, it became clear that practically every science task included some aspect of modeling. This result would have had the effect of obscuring other patterns that might exist in the data.

Finally, most of the Quantway lessons that explicitly address mathematical modeling as a process are to be found in the last sections of the written curriculum. One of the Quantway instructors told me that she did not really cover that section of lessons during the semester in which my student participants were taking the course. Therefore, asking those students to make connections between modeling tasks in Quantway and tasks from their science courses seemed unreasonable. By not including mathematical modeling as a distinct category in my framework, however, I am unable to comment on how this important idea appeared in the data. A study of how modeling appears in science tasks would be valuable.

The third and fourth research questions are intended to uncover the levels of quantitative literacy demand featured in student and instructor reports of tasks in general education science courses. To better analyze data with respect to these research questions, I relied on the taxonomy of quantitative literacy demand levels suggested by Frith & Prince (2009). In borrowing this taxonomy, I made a significant adaptation to achieve a better fit in terms of this present study.

The reader will note that I have only included five of the six QL-demand levels that appeared in the original taxonomy. In particular, I removed the level *expressing quantitative concepts*. This was also a methodological decision, and will be discussed further in the next chapter. The main reason was that, because the taxonomy was developed to analyze written curricular materials, this level did not translate well to an analysis of task descriptions given by students and instructors.

Finally, the methodology of this study relied on students to generate connections between tasks in Quantway and tasks in their general education science course. Although not represented in the original research questions as proposed at the start of this study, the data I collected revealed several interesting patterns with respect to student connection-making. In the framework below (Figure 4), I use four different categories to classify the types of connections students reported. This information provided a complementary lens through which to consider the research questions.

Conceptual Framework

Mathematical/Statistical Components of a QL Course

- Basic Numeracy
  - Perform basic arithmetic
  - Demonstrate understanding of magnitude (including scientific notation)
  - Use estimation skills
  - Demonstrate measurement sense (including units, precision, accuracy, error)
  - Use and interpret percentages
  - Understand absolute and relative change
  - Check the reasonableness of calculations
- Algebraic Reasoning
  - Understand the role of variables in an equation or relationship
  - Describe the effect that a change in one variable has on the others
  - Construct and use equations in one or more variables
  - Recognize covariant relationships (including direct and inverse variation)
  - Solve real world problems using the language and structure of algebra
  - Solve real world problems using ratios and proportions
- Data Analysis and Representation
  - Compute basic statistics including measures of center and measures of spread
  - Evaluate statistics that appear in a written report
  - Determine sources of bias in data
  - Describe the difference between correlation and causation
  - Evaluate the sampling strategy used in a study
  - Read, interpret, and make decisions based on visual displays of quantitative information
- Reasoning About Chance and Uncertainty
  - Use the language of probability to evaluate statements regarding risk or chance
  - Recognize the presence of uncertainty in measurements, predictions, or data
  - Apply rules of probability to solve real-life problems
  - Interpret statements involving conditional probability
  - Understand that mathematical models of real-life situations are subject to error
- Spatial/Geometric Reasoning
  - Solve geometric problems involving area, perimeter, or volume
  - Understand and translate between different units of measurement
  - Solve problems involving geometric scaling
  - Attend to geometric information on graphs, images, and diagrams

Figure 4. Conceptual Framework

Figure 4 (cont'd)

Levels of quantitative literacy demand required by science tasks

- Knowing
    - Understanding the meanings of verbal representations of quantitative terms and phrases
    - Knowing the conventions for the symbolic representations of quantitative information
    - Knowing the conventions for the representation of quantitative information on tables, charts, graphs, diagrams, and objects
- Identifying and distinguishing
    - Identifying connections between different representations of quantitative information
    - Identifying the mathematics to be done and strategies to do it
    - Identifying relevant and irrelevant information in representations
- Deriving meaning
    - Understanding a verbal description of a quantitative concept/situation/process
    - Deriving meaning from representations of data in context
    - Deriving meaning from graphical representations of relationships
    - Deriving meaning from diagrammatic representations of spatial entities
    - Translating between different representations
- Applying mathematical techniques
    - Use mathematical techniques to solve a problem, or clarify understanding – for example, calculating, estimating, measuring, ordering, modeling, applying algebraic techniques, etc.
- Higher order thinking
    - Synthesizing information and ideas from more than one source
    - Logical reasoning
    - Conjecturing
    - Interpreting, reflecting, evaluating

Figure 4 (cont'd)

Type of connection made by student

- Spontaneous Connection
    - Given a description of a Quantway task, the student recalls a science task that shares similar mathematical characteristics
- Prompted Connection
    - Given a description of a Quantway task, and a description of a science task, the student is able to describe a mathematical connection
- No Connection
    - Student is not able to describe a connection between a given Quantway task and a given science task.
- Incorrect Connection
    - Given a description of a Quantway task, and a description of a science task, the student is able to describe a mathematical connection, but the connection is, overall, mathematically inaccurate.

CHAPTER III: METHODOLOGY

Introduction

The purpose of this study was to explore with a group of community college students, and their science instructors, the quantitative literacy demands of general education science courses, and the ways in which students connect quantitative ideas across courses. I believe that a better understanding of this phenomenon would allow educators to proceed with a more informed perspective in terms of designing and implementing mathematics and science courses for non-STEM majors in two-year colleges. In seeking to understand this phenomenon, the study addressed four research questions: (a) Which mathematical/statistical components of a specific QL course (Quantway) do students report in tasks from subsequent general education science courses? (b) Which mathematical/statistical components of a specific QL course (Quantway) are to be found in instructor descriptions of tasks in general education science courses? (c) What levels of QL-demand characterize student descriptions of tasks in subsequent general education science courses? (d) What levels of QL-demand characterize instructor descriptions of tasks in general education science courses?

This chapter describes the study's research methodology and includes discussions related to the following areas: (a) rationale for the research approach, (b) description of the research participants, (c) summary of information needed to answer the research questions, (d) overview of research design, (e) methods of data collection, (f) methods for analysis and synthesis of data, (g) ethical considerations, (h) issues of trustworthiness, and (i) limitations of the study. The chapter concludes with a brief summary.

Rationale for Qualitative Research Design

In a broad sense, qualitative educational research is grounded in a philosophical position that is primarily concerned with how we experience, interpret, and understand the world at a particular moment in time (Glesne, 2011). The intent of qualitative research is to examine a social situation by allowing the researcher to see the world through other's eyes, and to achieve a holistic understanding of phenomena (Schram, 2003; Schwandt, 2000). Qualitative methodology emphasizes discovery and descriptions, with a general focus on distilling and interpreting the meaning behind human experiences (Bogdan & Biklen, 2003). This focus largely contrasts with that of quantitative research, in which the intent is usually to test hypotheses, establish facts, distinguish relationships between variables, and make generalized predictions based on data.

Early in the formation of my ideas for this dissertation, I realized that quantitative methods would be unlikely to elicit the kinds of rich data necessary to address the proposed research questions. Instead, I came to see that various features of qualitative research would fit well with my ideas for the study. Some of these features included (a) understanding the processes by which events occur, (b) developing an understanding of a phenomenon that is situated in context, (c) facilitating meaningful interaction between the researcher and the research participants, (d) adopting an interpretive stance, and importantly, (e) maintaining design flexibility. Finally, qualitative methods are often useful when exploring phenomena around which there is little existing research (Glesne, 2011).

Rationale for Case Study Methodology

Within the overarching framework of qualitative methodology, this study was well suited for a case study design. Case study is a research methodology that provides a rich description and analysis of a phenomenon social unit, or system bounded by time or place (Cresswell, 2013; Stake, 1995). In particular, case study is an ideal design for understanding and interpreting educational phenomena. As Merriam (1998) states [italics added],

> A case study is employed to gain an *in-depth understanding of the situation* and meaning for those involved. The interest in the *process* rather than outcomes, in context rather than a specific variable [and] in *discovery* rather than confirmation. Insights gleaned from case studies can directly influence policy, practice, and future research (p. 19).

The present research fits well with Merriam's criteria because I sought to understand how and when community college students and instructors connect quantitative literacy with general education science courses, and the relationships students themselves perceive between those educational experiences. There are several different types of case study, including heuristic, descriptive and particularistic (Merriam, 1998). The specific methodology I chose for this study was comparative case study, which has its roots in the field of anthropology, and which Guba and Lincoln (1981, p. 119) describe as useful for "interpreting the meaning of… descriptive data in terms of cultural norms…community values, deep-seated attitudes and notions".

The Research Sample

A purposeful sampling procedure was used to select the study participants. Purposeful sampling is a method that is typical of case study methodology, and is used to discover as great a variety of information about the phenomenon of interest as possible (Glesne, 2011). As a researcher, I was interested in finding individuals who experienced quantitative literacy (QL) instruction as part of their community college mathematics coursework, and who would be able to speak about their experiences in a subsequent general education science course. The criterion for selection of research participants was as follows: First, all participants had passed (with a grade of C- or higher) a two-semester sequence in quantitative literacy, called Quantway (Carnegie Foundation for the Advancement of Teaching, 2012) in Spring 2015 at a large urban community college in the Midwest. Second, all participants were still enrolled at that same community college, and were scheduled to take a science course to fulfill general education (non-major) requirements in Fall 2015. I wanted to find students who were taking a variety of different science courses, not in an attempt to generalize my findings across science courses, but to allow for as wide a variety of student perspectives as possible. This multiplicity of perspectives, I hoped, would reveal many connections between QL instruction and community college science courses for non-STEM majors.

The choice to only recruit students enrolled at a specific community college was made in order to secure participants who had experienced roughly the same instantiation of a QL curriculum. As discussed in the previous chapter, there is no standard definition of what counts as QL in colleges, and therefore a QL course at one institution may look quite different from a course at a different institution. Although I could have studied the experiences of students with a variety of QL curriculum, Quantway had several factors in its favor: It is the largest (by enrollment) QL program offered in the country, which made finding a research site more straightforward. Quantway is also a well-established program, and many future readers of my work will be familiar with it. The Carnegie Foundation has built a substantial professional development network in which community college instructors receive training and course materials that are intended to create a relatively consistent curriculum across the country. Finally, I already had a working relationship with two Quantway instructors, who were able to put me in contact with representatives from the Carnegie Foundation. These contacts proved vital in securing copies of the written curriculum for Quantway.

The final list of research participants included six community college students and the instructors of their general science courses. Two of the students were enrolled in the same section of an introductory astronomy course. Purposeful selection was also based on variation across certain distinguishing characteristics. Although all participants completed Quantway, there were differences among them including gender, previous collegiate mathematics experiences (other than Quantway), career aspirations, and age. The students were enrolled in the following general education science courses for the duration of this study: Introduction to Astronomy, Principles of Geology, World Geography, Human Anatomy & Physiology, and Cellular Biology.

In Summer 2015, I recruited students through an intermediary–their Quantway instructors. I met with the Quantway instructor at each campus and explained the purpose and nature of my research. I then sent the Quantway instructors a letter asking for volunteers, which they sent to their former students on my behalf. Eleven students responded to this email, and I sent them a brief demographic survey (Appendix B). Ten students returned the survey, and of those ten, seven were enrolled in a science course in Fall, 2015. Before the semester began, I emailed the students to ensure their participation in the research program. One of the students had changed his plans with respect to his class schedule and was no longer taking a science course. The remaining six agreed to participate in the research program (Table 4), and I began the process of scheduling initial interviews.

Participant Descriptions

Carol is a white woman in her second year of college. She was the youngest participant in the study, and had been homeschooled throughout high school. In our first interview, she discussed her desire to become an elementary school teacher, and her plans to transfer to a four-year private college. Carol described herself as a good student, who had always done well in mathematics in high school. Her college placement score had been just high enough to qualify for college algebra, but her advisor encouraged her to take the Quantway sequence. At the time of our interviews, Carol was unsure whether or not she would be able to transfer her credits from Quantway to the four-year college.

Gary is an African-American man in his mid-twenties, who has been in and out of college for seven years. During those years he had changed his major twice, worked different jobs, and even considered a military career. At the time of our first interview, he was planning to become a paramedic or other first responder. He had joined a volunteer fire department and was trying to finish an associate's degree so he could begin studying to become a paramedic. He told me that mathematics had always been a struggle for him, but that he really enjoyed the Quantway sequence.

Kelsey is a white woman in her early twenties, pursing a career in physical therapy. She was excited to participate in this study, and emailed me several times before our first interview to make sure she had done everything necessary to participate. Throughout our interviews, she often spoke with enthusiasm about her experiences in Quantway. She was in her final semester at the community college and was preparing to transfer to a state university.

Erica is a white woman in her early twenties. She was soft-spoken, and often apologetic about her mathematical abilities. She told me that she was interested in getting into the film industry, and had already worked on one independent film while in college. In our first interview, she told me that she had liked mathematics until middle school, but struggled in high school algebra. After that, she claimed, she had only bad experiences with mathematics until taking the Quantway sequence.

Daliah is an African-American woman in her early twenties, who was attending community college part-time while working as a teller at a local bank. She was attempting to complete an associate's degree in finance, and was taking a biology class simply because it fit her schedule. She told me that she was an average student in high school, but had found mathematics to be her most difficult subject. In our first interview, Daliah told me plainly that she "hated math", but had enjoyed both the content of Quantway, and her instructor.

Heather is a white woman in her early twenties, with a passion for gourmet cooking and entertaining. She told me she wanted to pursue a career in the hospitality industry, but was unsure exactly what aspect of the industry interested her the most. In high school, Heather had disliked mathematics until her senior year when she "finally had a great teacher". Since then, she told me that she enjoyed seeing connections between mathematics and her everyday life. As Heather told me, "there's a lot of math in cooking".

Table 4.

Student participant matrix

Name	Gender	Previous College Math Courses	Science Course	Career Aspiration	Age
Carol	F	Quantway	Principles of Geology	Elementary Education	19
Gary	M	Quantway and College Algebra	Introduction to Astronomy	Associate of Arts	26
Kelsey	F	Quantway and College Algebra	Human Anatomy and Physiology	Physical Therapy	21
Erica	F	Quantway	Introduction to Astronomy	Film Studies	20
Daliah	F	Quantway and College Algebra	Cellular Biology	Finance	20
Heather	F	Quantway	World Geography	Hospitality Services	22

Once I had secured the student participants, and knew which sections of their science courses they planned to take, I contacted the instructors of those courses. All five of the instructors agreed to participate in the research program. I collected demographic information using a survey (Appendix C), and their demographics are summarized below (Table 5). The instructors varied in age and experience. The most senior instructor had been teaching courses in her discipline since completing graduate school in the 1981. Three were part-time adjunct instructors, and two of those were also teaching courses at a different community college. In order to help the reader remember which instructor taught each course, I chose pseudonyms that reflect their respective disciplines.

Table 5.

Instructor participant matrix

Name	Gender	Course taught	Years teaching this course	Job description
Prof. Geol	F	Principles of Geology	15	Associate Professor of Geology
Prof. Astro	F	Introduction to Astronomy	3.5	Adjunct Faculty, Physics Department
Prof. Physio	M	Human Anatomy and Physiology	7	Lecturer of Biology
Prof. Cell	M	Cellular Biology	4	Associate Professor of Biology
Prof. Geog.	F	World Geography	6	Adjunct Professor, Earth Science

Information Needed to Conduct the Study

This multicase study focused on the experiences of six community college students in a large urban community college in the Midwest. In seeking to understand the connections these students (and their science instructors) made between quantitative literacy instruction and general science instruction, I developed four research questions. To answer these questions, I developed a conceptual framework, and determined what information would be needed to answer the questions. This information fell roughly into four categories: (a) contextual, (b) perceptual, (c) demographic, and (d) theoretical. Contextual information included descriptions of the setting in which the study occurred, including the cultural and environmental factors. These factors include history of efforts in this particular community college to improve students' QL, the vision and objectives of the Quantway course, the organizational structure with respect to pre-requisite and co-requisite course requirements, and a description of the curriculum used in both Quantway and science courses. Perceptual information included community college students' perceptions of how and when QL components surfaced in their general science courses, the levels of quantitative literacy demand required by general science courses, and reports from general science instructors as to the quantitative literacy aspects of these courses. Demographic information included information pertaining to study participants, including major, previous mathematical experiences, age, gender and ethnicity. Furthermore, I conducted an ongoing review of literature to provide theoretical grounding for this study.

Overview of the Research Design

The following list summarizes the steps used to carry out this research, including early groundwork from the 2014 – 2015 academic year. Following this list is a more in-depth discussion of each step.

1. A review of selected literature was conducted to study the contributions of other researchers in the broad areas of quantitative literacy instruction, general education science instruction, developmental mathematics in community colleges, and knowledge transfer between mathematics and science courses.
2. Contextual information was gathered through analysis of the written Quantway

curriculum (Carnegie Foundation for the Advancement of Teaching, 2012) to uncover the objectives and vision for the course. Additional contextual information was gathered with respect to how Quantway fits in the larger web of course offerings at the research site.

3. A pilot study was conducted to determine: (a) whether it was reasonable to expect community college students to notice aspects of a previous QL course during a general education science course, (b) the types of connections students might make between these educational experiences, (c) the topics within a general science course that might require students to exercise their quantitative literacy, and (d) science instructor perceptions of QL in their own courses.
4. Following the proposal defense, I acquired IRB approval to proceed with the research. This process involved outlining all procedures and processes needed to ensure adherence to standards for conducting research involving human participants, including participants' confidentiality and informed consent.
5. Potential research participants were contacted, using two Quantway instructors as intermediaries. Those students who agreed to participate were sent a brief electronic survey. This survey was designed to collect demographic data and to ascertain which science courses they planned to take.
6. Six student participants were identified and the researcher invited their general science instructors to participate in the research. Two of the students were took same section of a general science course, so only five instructors were included. All five instructors agreed to participate in the research.
7. Semistructured, in-depth interviews were conducted with five community college science instructors early in Fall 2015

8. Instructor interview responses were analyzed within and across courses.
9. Semistructured, in-depth interviews were conducted with six community college students during early Fall, 2015
10. Student interview responses were analyzed within and across cases.
11. A second round of interviews was conducted with six community college students to follow up on issues that arose during the first interview, and provide additional opportunities for participants to report connections.
12. A focus-group was conducted with four of the six student participants to cross-check data collected through interviews, and further discuss levels of quantitative literacy demands of their science courses.

Prior to the Study

Literature Review

An ongoing and selective review of literature was conducted to inform this study. Three areas of literature were identified: (a) Quantitative literacy, with a specific focus on how QL is operationalized through the Quantway curriculum, (b) Research reports of the quantitative demands of general science courses, with a focus on potential overlap with the Quantway curriculum, and (c) Research and literature on factors that influence student connection-making across mathematics and science courses. The focus of the review was to gain a better understanding of the aspects of QL that appeared in Quantway, the conditions under which students might make connections between Quantway and their subsequent general science courses, and the likelihood of QL appearing in general education science courses in the first place. In addition, the review pointed to gaps in our knowledge of the purpose of QL instruction for students, particularly with respect to the claim that QL courses prepare students for the quantitative demands of subsequent academic courses.

Contextual Information

Following the literature review, I identified a particular community college as a potential research site. This institution has a long track record of QL instruction, a large pool of students from which to draw research participants, and demonstrated an eagerness to work with me in conducting this study. I gathered information on the college's demographics, enrollments in QL courses, pass rates in those courses, and other forms of demographic data. I collected information on the Quantway curriculum used in this institution, obtained a complete copy of the instructor's materials from the publisher, observed a Quantway class, and had lengthy discussions with two Quantway instructors about course objectives and vision. I searched the written curriculum for prominent mathematical and statistical components, which formed an early coding scheme for pilot data.

Pilot Study

In Spring 2015, I conducted a small pilot research project in which I interviewed three community college students and one community college science instructor. The purpose of this pilot study was threefold: First, I wanted to ascertain whether or not it was reasonable to expect students to make any connections whatsoever between their QL course and the science courses in which they were then enrolled. The students did, in fact, make several interesting connections. Second, I wished to test interview protocols on both students and an instructor. The process of interviewing led to important changes in the protocol, specifically in the examples I used to prompt students' thinking, and in the language I used to communicate ideas from math education to instructors whose expertise lies in other areas. Finally, I wanted to use the results of the interviews to test my initial coding scheme. As a result of coding pilot data, I expanded certain coding categories, and collapsed or refined others (see Appendix D for a complete record of changes to the coding scheme throughout this dissertation).

IRB Approval

Following the literature review and pilot study, I developed and successfully defended a proposal for this study that included the background/context, problem statement, purpose statement, and research questions outlined in chapter one; a literature review similar to that included in Chapter 2; and the proposed methodological approach outlined in this chapter.

Once the proposal was successfully defended, the researcher applied for approval from the Michigan State University institutional review board for permission to conduct research involving human subjects. This application included a summary of the research proposal, including all data collection instruments and informed consent documents. The research was designated Exempt by the IRB.

Data Collection Methods

Multiple data collection methods were used for attempting to gain an in-depth understanding of the phenomenon under study. In qualitative research, such methods add rigor, breadth and depth to the study and provide corroborative evidence for the claims made with respect to data (Creswell, 2013). Therefore, I relied on a number of different sources of data, including the pilot study, a demographic survey, document summaries, multiple rounds of individual interviews with students and instructors, and a focus group with students.

The interview was the primary method for data collection in this dissertation. There are three reasons why interviewing was chosen for this study: First, because of its potential to elicit rich, thick descriptions (Geertz, 1973). Second, the nature of semi-structured interviews allows the researcher to ask participants to clarify statements and probe for additional information.

Finally, a major benefit of collecting data through interviews is that they offer a potential to capture individual perspectives of events or experiences (Cresswell, 2013).

The interview is a fundamental tool in many forms of qualitative research (Glesne, 2011), because it is an attempt to understand the world from the point of view of the research participant, and to derive meaning from their life experiences. Patton (1990, p. 278) note, “qualitative interviewing begins with the assumption that the perspective of others is meaningful, knowable, and able to be made explicit”. In choosing this method of data collection, I was assuming that a legitimate way to gather data is by listening to the accounts told by actual students and instructors. My intention was to capture the meaning of their experiences, in their own words.

Interviewing, as a form of data collection, is not without limitations. Not all people are cooperative, not all articulate well, not all are equally perceptive, and not all reflect deeply on classroom experiences. The person conducting the interview must possess certain skills including tact, the ability to phrase questions well, the perception and inclination to follow-up on important points, the ability to probe for additional data, and to know when to move on. The interviewer must help the participant to feel comfortable and confident that his or her experiences matter, and that their confidentiality will be protected. Finally, interviews are not neutral tools of data collection but are inherently tied to the context in which they take place (Schwandt, 1997). This context includes both the physical location and time of day, as well as the time during the semester. For this study, I felt that the promises of semi-structured interviewing as a research tool outweighed its limitations.

Interview Schedule and Pilot Interviews

With guidance from members of the dissertation committee, I used the study research questions to develop two sets of interview questions–one for use with instructors, and one for use with students. I constructed a data use matrix to illustrate the relationship between the interview questions and the research questions. During a pilot study, the researcher conducted three interviews using the initial sets of questions. The preliminary themes that emerged from this pilot centered on students' perceptions of QL components in their science courses, students' perceptions of quantitative literacy demand required by their science courses, and instructor's perceptions as to what aspects of QL appear in a science course. Based on responses from the pilot interviews, as well as feedback from the dissertation committee, the interview questions were adjusted to include more specific references to the Quantway curriculum, to make certain questions more open-ended, and to include specific prompts for additional information. These adaptations allowed the researcher opportunities to follow new directions that might emerge during an interview. The final interview protocols for students are included in Appendices E, F, and G and the final instructor interview protocol is included in Appendix H.

Interview Process

Interviews with instructors took place during August and September 2015, while student interviews took place between September and December, 2015. Before the commencement of each interview, the participant was asked to read and sign an informed consent form (Appendix I) required for participation in this study. All interviews were conducted face-to-face and were digitally recorded in their entirety. Each participant was enumerated $50 per interview (in the form of a VISA gift card), using funds provided by a dissertation continuation fellowship from the College of Natural Sciences at Michigan State University. During the interview, the researcher kept field notes of the conversation, and on completion of each interview the audio was transcribed in clean verbatim. Field notes included references that participants made to specific textbook pages, assignments and diagrams. I purchased a copy of each science textbook so that I might refer to it when re-reading the transcripts.

The logic of inquiry necessitated that the instructor interviews precede the student interviews. This is because the student interview protocol calls for the researcher to occasionally prompt the student for their thoughts about specific tasks in the general science course (e.g. carbon dating, plate tectonics, the flow of blood through a constriction). I am not an expert on fields such as astronomy or human physiology, and neither did I have much prior knowledge as to which topics constitute a course in introductory astronomy (for example) at this particular community college. Therefore it was necessary to first elicit from the instructors a list of topics that *they* felt contained important QL components. These instructor reports allowed the researcher to more effectively probe students about their experiences in general education science classes during the student interviews and focus group.

Focus Group

Group interviews contain elements of both individual interviews and participant observation (Glesne, 2011) but stand apart as their own qualitative research method (Liamputtong, 2011). A focus group is essentially a group discussion focused on a single theme (Cresswell, 2013). The goal of a focus group is to generate open, impromptu conversations that address the selected topic in depth. Liamputtong (2011) states that researchers can obtain a more complete and revealing understanding of issues when the discussion takes place in an atmosphere that fosters a range of opinions. As such, focus groups are planned and structured around specific questions, but are also flexible in responding to the direction of the participants. Krueger and Casey (2009) list several uses for focus groups that made this choice of data collection a good fit for this study. These include: (a) the potential to elicit a range of feelings, opinions, and ideas, (b) the chance to understand differences in perspectives, (c) the opportunity to drill down into specific factors that influence opinions, and (d) the capability of the group to generate new ideas.

As with any data collection instrument, focus groups also possess certain limitations. One of these limitations is the possibility that *group think* (Conrad & Serlin, 2006) will occur. Other limitations include logistical difficulties in organizing a meeting around multiple participants' schedules, and the likelihood that one or more invited participants will not be able to attend. Finally, group conversations require that the researcher balance conversation management and the need to extract data with the desire to value the perspectives of all participants. This requires strong facilitation and inter-personal skills.

At the conclusion of all student interviews in early December, one focus group took place involving four of the six student research participants. All six students were invited to participate, but two were unable to find time in their schedules to attend. The group conversation lasted one hour and fifteen minutes. The purpose of the conversation was threefold: (a) to allow the students to add to their statements from individual interviews and thus provide additional data, (b) to explore the issue of QL demand levels in more depth, and (c) to provide a measure of trustworthiness and credibility to the study. Although the format was open-ended, a skeleton framework was used to facilitate the conversation (Appendix G). The framework hinged on two important issues: First, would students provide any additional instances in which QL arose during general science instruction that were not mentioned in previous interviews? Second, how would they themselves describe the levels of quantitative literacy demand required by specific tasks in their respective courses?

Methods for Data Analysis and Synthesis

One persistent challenge throughout the phases of data collection, synthesis, and analysis was to make sense of the sheer volume of data that arose through qualitative inquiry. My main concerns were to follow up on significant patterns and to remain faithful to the research plan as approved by the dissertation committee. This later concern became particularly challenging when faced with myriad paths over which to pursue interesting ideas. It required discipline to stick with the original research questions and many potential avenues of inquiry remain open, even at the writing of this dissertation. With respect to the former concern, to reduce the volume of data in a sensible way, Merriam (2014) advises researchers to conduct data analysis simultaneously with the process of data collection. In following this advice, I was better able to collect focused, manageable, and novel data. For example, by proactively analyzing a significant portion of the data from the first round of student interviews, I was able to ask more pointed questions in the second round.

The initial phase of analyzing data included the assignment of codes associated with the categories and descriptions of the conceptual framework outlined in the previous chapter. The researcher used Microsoft Excel to prepare spreadsheets that served as repositories for sections of transcribed data. One spreadsheet was created for each student research participant, and for each instructor participant. The spreadsheets were organized by the descriptors under each category of the conceptual framework. As the process of coding proceeded, the spreadsheets were enlarged to include new themes as they emerged from the data.

Coding for QL: Mathematical/statistical Components

Transcripts were coded based on specific *tasks*, rather than line-by-line or turn-by-turn. For example, if a student began to tell me about a task involving carbon dating, I coded the entire conversation surrounding that same task as one unit of analysis. The same unit was often coded for multiple mathematical/statistical components. These components were taken from the conceptual framework, and were organized into five broad categories according to the framework presented at the end of Chapter Two. These categories were: Basic Numeracy, Algebraic Reasoning, Data Analysis and Representation, Spatial/Geometric Reasoning, and Reasoning about Chance and Uncertainty. Each major category was composed of several specific sub-categories (see Appendix J for the full coding scheme). Below is a sample from an interview with Erica, to demonstrate how the coding scheme was employed (See Appendices K and L for sample segments of coded transcripts):

Erica: When we talked about – the last thing we talked about was like the chances of there being life somewhere else in the universe, using the probability, like the universe is so big there probably is a chance that there's some sort of life; maybe not intelligent life. But it actually takes a lot – like it has to be exact conditions for life to form because it's a really strict formula for –

IN: Strict, as in, what is necessary for life to form–

Erica: Yeah. Temperature, water, sun, heat and –

IN: Right amount of gravity so we don't –

Erica: Yeah, so it's kind of hard for that to happen but since the universe is so big, it's probably like there is something. And we just guessed at some of the numbers, so it's not exact, right? But it's [the Universe] so large that when you multiply the number of planets, or whatever, you still would think there should be some life out there.

Here is how I coded this task, which I labeled the *extra-terrestrial life* task:

P1. (Use the language of probability to interpret statements regarding risk or chance)
P2. (Apply rules of probability to solve real-life problems)
P3. (Recognize the presence of uncertainty in measurements, predictions, or data)
N1. (Perform basic arithmetic)
N3. (Use estimation skills)
N5. (Use and interpret percentages)

In terms of broader categories, the extraterrestrial life task is therefore coded as *Basic Numeracy*, and *Reasoning about Chance and Uncertainty.*

In analyzing all of the interview transcripts, it became helpful to name each task as it appeared in student and instructor reports. This allowed me to compare same-task descriptions a student gave to those given by his/her instructor. For example, here is a segment of Professor Astro's description of the *extra-terrestrial life* task:

PA: I'm not sure they really, well maybe no one really does, but they don't understand how big the Universe really is. The sheer number of stars, planets, planetary systems–it's mind-boggling.

IN: And how do you help them make sense of that kind of scale, those numbers?

PA: Not very well! I mean, what does it mean that there are, oh, 10^{24} planets in the Universe? Who knows what that number even means?

IN: Right, is that like the number of grains of sand on a beach, or–

PA: Right. It's so big that, well, one activity I like to do with them is, especially if we have some extra time, is to think about the possibility of life existing somewhere else in the Universe.

IN: Oh, that's really interesting.

PA: Yeah, and it's a good way to help them interpret the sheer size of the Universe. Because you take your different parameters, what percent of all planets are far enough from a star to be warm enough to support life, but not too warm? What percent have the right atmosphere? What percent have the right size? All these things. So we just put values on these parameters, and the thing is, you can make them as small as you want. Really small percentages. But when you consider the number of planets out there–well, the likelihood is actually pretty decent.

IN: Really?

PA: Absolutely. But then this gets into a discussion of aliens, and someone mentioned [the movie] Contact, and it turns into a fifteen-minute discussion. And the result is I don't get through all my slides.

Here is how I coded this task for mathematical/statistical components:

P1. Use the language of probability to interpret statements regarding risk or chance
P2. Apply rules of probability to solve real-life problems
N1. Perform basic arithmetic
N2. Demonstrate understanding of magnitude (including scientific notation)
N3. Use estimation skills
N5. Use and interpret percentages

In terms of broader categories, the extraterrestrial life task is therefore coded as *Basic Numeracy*, and *Reasoning about Chance and Uncertainty.*

Coding by task is helpful because it allows the researcher to consider a natural unit of classroom activity (the task) rather than an arbitrary unit such as a spoken turn, or even single lines in a written transcript. The use of larger categories (such as *Basic Numeracy*) is helpful because they provide a "big picture" image of the mathematical/statistical demands of general science tasks, thus allowing the researcher to more easily observe broad trends, both within a single course, and across multiple science courses. Notwithstanding these benefits, coding by larger categories tends to obscure other aspects of the data that may be important. For example, in the above transcripts, Erica did not mention that one purpose of the task was to help make sense of very large numbers. The fact that she still mentioned the need for performing multiplication caused me to code the task for *Basic Numeracy*, but the types of numeracy in Erica's description are not identical to the types mentioned by Professor Astro.

In reporting data in the following chapter, I will typically stick to larger categories and broad trends. In my own coding documents, however, I have the capability for a more fine-grained analysis of sub-components, and I will occasionally bring this kind of secondary analysis to bear.

Coding for Levels of QL-demand

Each task was also coded based on its level of QL-demand (as suggested by Frith & Prince, 2009). In their work, these authors described six levels of QL-demand, but as can be seen from the conceptual framework from the end of Chapter Two, I used only five of their levels in coding my data. In particular, I decided to eliminate the level *Expressing Quantitative Concepts* for the following reason: Frith and Prince (2009) originally designed this particular framework to evaluate the QL demands of written science curriculum. Written curriculum was the only source of data in that paper, and in all subsequent papers where this framework appears (see Frith, 2011; Frith, 2012; Frith & Gunston, 2011; Frith et al., 2010). In examining written materials, it is logical to ask if a situation would require students to express quantitative concepts, or simply to consider information in a passive way. Frith and Prince (2009) note that not all curricular materials require this stage (e.g. the description of a biological process in a textbook for first-year medical students did not require the reader to *express* anything–reading and understanding the diagram could be an entirely passive event from the perspective of the student).

In my study, however, I was only looking at reports of tasks, whether mentioned by an instructor or a student. *Every* task mentioned by a student or instructor required some action on the part of the students, and this action meant expressing a quantitative concept. Rather than code every task with this level, I eliminated it from the coding scheme, to provide better resolution as I focused on the other levels of QL-demand.

A second question I needed to answer with respect to the Frith & Prince (2009) framework was whether or not the six (now five in my adapted framework) represented a continuum. That is, if a task required a student to engage in a higher level, such as applying mathematical techniques, should I code that task as automatically requiring all the lower levels of QL-demand? Arguments might be made for both the affirmative and the negative. In their original paper, the authors treated the QL-demand levels as a continuum, although they did not provide an explicit theoretical reason for doing so. The task they chose as an example (hemoglobin and myoglobin binding curves) required all six levels of QL-demand, and the authors hypothesized how a students' thinking might progress through the six levels, one at a time.

In this dissertation, however, I do not apply the framework for QL-demands as if it were a continuum. Perhaps the strongest evidence against the continuum method lies in the notion that a student is capable of applying a mathematical technique (such as adding fractions) without deriving meaning, or even knowing the conventions for the symbolic representation of numbers. The classic case of Benny (Erlwanger, 1973) comes to mind as an example of a student who could apply mathematical techniques without understanding their meaning, but there are multiple instances of this in the mathematics education literature. Indeed, a driving motive behind the goal of teaching for conceptual understanding is that students frequently apply mathematical procedures without understanding what is going on (Hiebert & Lefevre, 1986). My personal experience as a high school teacher tends to support the idea that a student might engage with some levels of quantitative demand without first thinking through lower levels.

Finally, I explored later work by the original authors of the framework and found instances in which the framework was *not* applied as a continuum (e.g. Frith & Gunston, 2011). Given the authors' own use of the framework in such papers, my own experiences as a classroom teacher, and the mathematics education literature on conceptual vs. procedural understanding, I decided (for this study) against treating the framework as a continuum. Thus, a task might be coded for *higher order thinking*, without needing to code it for *applying mathematical techniques*, or coded as *applying mathematical techniques* without having to code it for *deriving meaning*.

Coding for Connection Types

When I coded the first instructor interviews, I only had codes based on mathematical and statistical components, and levels of QL-demand. After a first pass through the student interviews, it became apparent that several codes were too overlapping, and I collapsed similar codes (e.g. *interpret percentages in a variety of contexts,* and *apply percentages to solve a real-*

life problem). It was during the data analysis phase that an entirely new category of coding, *types of connections students make*, became apparent. As referenced in the conceptual framework at the end of chapter two, I noticed four different ways in which students connected tasks in their general science course with a task from their QL course. The student might make the connection *spontaneously*, they might make a *prompted* connection, they might make an *incorrect* connection, or they might make *no connection* at all.

For example, here is how I applied this coding scheme to a segment of my discussion with Carol:

IN: What about volume? If the Earth were a basketball-

C: Oh, yeah we did that one. Calculating how big a sphere the inner core, outer core, yeah.

IN: So when you say how big a sphere? I mean, is the mantle a sphere?

C: Well, I guess diameter. We had to figure the diameter inside the basketball. And we had to convert from kilometers to centimeters or maybe millimeters? Yeah. Millimeters.

IN: And can you see a connection between this activity and the Quantway lesson I mentioned about acreage in the city?

C: So, yes. Once you point it out. Sure, they both have to do with, like, a scale? I mean, using a model at scale to make calculations.

In this exchange, I was probing to see how Carol might describe the similarities between a task from her QL course (in which she had to transfer information about the size of a city to a particular two-dimensional representation) and a task in her geology course (in which she had to sketch a model of the Earth's interior as if it were a basketball). I coded this exchange as an example of a *prompted connection*, because I provided the science context before the student saw a connection to a task in her QL course. If Carol had volunteered the basketball scenario, without my probing, this task might have been coded as a *spontaneous* connection.

It is worth noting, at the risk of redundancy, that a students' description of a single task was coded in at least two different ways. The task was first coded for specific mathematical/statistical components, and then also coded by level of QL-demand. Finally, if the student made a connection between the task and Quantway, or if the researcher attempted to probe for such a connection (even if no connection was made), the exchange was coded for *type of connection made*. Not all tasks were coded for type of connection, because many descriptions of tasks arose while talking about other tasks, not as a result of the researcher first providing a specific task from Quantway.

Document Summary

Frequently, during instructor and students interviews, a participant would direct my attention to physical documents to explain a science task. These were primarily textbooks or lab manuals, although instructors occasionally gave me copies of their syllabi and even assessments. Although I had not proposed to conduct document analysis as part of the research project, it became apparent that these documents offered contextual clues to help make sense of task reports. For example, students often pointed to specific graphs in their textbooks when describing science tasks. Within the written transcript, such references lack significant meaning because the reader cannot see the textbook page. I attempted to record the location of such references in my field notes.

Furthermore, the documents tended to shed light on the QL-demands of tasks. For example, when analyzing Kelsey's description of the *muscle contraction task*, she referred to a specific graph as something she needed to comprehend in order to complete the task. Examining the graph closely reveals that in order to interpret it, the student would need to attend to two different units of scale. If I were to restrict my coding to strictly what Kelsey had verbalized, I would miss a significant QL demand of the task.

Therefore, I decided to use a document as a source of data, but only if a student or instructor directly referenced it in an interview. In making this decision, I was placing my level of inference at one level beyond the literal words used by a participant. For each document that appeared in an interview, I completed a brief document summary form (Appendix M) that put each document in context, explained its significance, and gave a brief content summary.

Inter-rater Reliability

I prepared two samples of transcribed interviews to test my refined coding scheme. I shared these samples, along with an initial list of codes and descriptors, with one of the Quantway instructors at the research site. Discussion with this instructor was extremely helpful in both confirming certain coding designations and providing fresh insights as to how certain phrases might indicate aspects of QL. In the sample transcriptions coded by the Quantway instructor and myself, inter-rater reliability was just over 85% (36/42 codes agreed). After yet another pass through the data, I asked a fellow graduate student to code sections of the transcripts using a refined coding scheme. This student coded for both mathematical/statistical components as well as QL-demand levels. Inter-rater reliability between the fellow graduate student and myself was just over 87% (33/38 codes agreed). Both the Quantway instructor and the fellow graduate student assigned slightly *more* codes to each section of transcript than I did. This indicates that I was, perhaps, too conservative in assigning codes to the statements given by students and their science instructors.

Synthesis

In general, the coding process breaks interview data into separate categories, so that the researcher can attend to the data in greater detail. This process was followed by a synthesis stage, which involved reconstructing the fragments to produce a holistic and integrated description. I took an approach to synthesis that looked for patterns and themes that collectively described the research environment, including an exploration of contradictory instances that did not agree with a more general pattern. To accomplish this, I used a three-stage approach suggested by Glesne (2011). In the first stage, I examined and compared themes *within* categories. Next, I examined and compared themes *across* different categories. Finally, I compared and contrasted my results with respect to prior research on issues connected with the broader literature base. This is not to say that the three stages occurred in distinct chunks. Rather, I took an iterative approach throughout the synthesis stage that resulted in occasionally blending stages together, much like layers of rock tend to interlock at their boundaries.

After all the interviews were coded, I prepared written narratives based on each of the spreadsheets. These narratives were helpful in cross-examining the data. Based on a thorough analysis and synthesis of data, I was able to move forward with thinking about the broader implications of this research. I formed several conclusions, highlighted specific questions that remain unanswered, and proposed specific research-related recommendations.

Ethical Considerations

Issues related to the protection of the participants are of concern in any research study (Schram, 2003). In the process of conducting social science research, it is the responsibility of the investigator to inform participants of their rights, and protect those rights. This study involved the assistance of many participants, and a basic premise of such work is that the participants are well informed about the purpose of the study. As issue of first order is the way I treated personal information about the participants. I did not expect that any serious ethical threats would arise with respect to any of the participants, but I nevertheless employed various strategies to ensure the protection of participants' rights.

I obtained informed consent from each participant throughout the course of the study. This took the form of written, signed consent to voluntarily participate in the study, with the understanding that any participant was free to cease participation at any time. Enumeration was built into the study in a tiered structure, so that a participant who chose to only sit through one interview would still receive some compensation for their time. In addition, I kept the participants' rights and interests in mind throughout the reporting of data, and will continue to do so throughout future dissemination of results. Names and other signifying characteristics were kept confidential. Instructors did not know which, if any, of their students were participating in the research project. Instructors did not know which other instructors participated in the research.

I took multiple measures to secure physical data, which including my field notes, digital recordings, and typed transcripts. These measures included storing all written material in a locked filing cabinet within my locked office, and storage of all digital data on a password protected external hard drive. Overall, I did my best to ensure that no one other than the researcher had access to such material.

Issues of Trustworthiness

In seeking to establish the trustworthiness of this study, I choose to draw on the criteria set forth by Lincoln and Guba (1985), which represents something of a break from traditional measures used in quantitative studies. Given the significant differences between quantitative and qualitative research methods, it seemed logical that I seriously attend to what counts as trustworthiness in terms of qualitative research methods. For example, how can a researcher address issues of validity (the extent to which something measures that which it purports to measure) or reliability (the consistency with which something is measured over time) without traditional quantitative tools?

To this end, Lincoln and Guba (1985) suggest that qualitative methods be judged by the following criteria: Credibility, Dependability, Confirmability, and Transferability. In this section, I briefly address the measures taken to attend to each criterion. Other qualitative researchers suggest different criteria, but in general, attending to trustworthiness means finding ways to control for biases that might be present in the design, implementation, and analysis of the study.

Credibility

Cresswell (2013) indicates that credibility is the qualitative analog to the quantitative notion of validity. As such, the extent to which qualitative research is credible depends on the extent to which the findings are accurate from the perspective of the reader, the participants, and the researchers (see also Lincoln & Guba 1985, 1986; Mason, 1996; Merriam, 2009). In qualitative research, the focus is less on attempting to *verify* results and conclusions, and more on *interpreting* the validity of conclusions (Mason, 1996).

One way that researchers can demonstrate credibility is by showing that there is a good match between the logic of inquiry and the research questions. It is important to consider the relationships between various research design components such as the purpose of the study, the conceptual framework, the research questions, and the research methods. The extent to which there is a tight fit between these components is called *methodological validity*. Another form of credibility is called *interpretive validity* (Altheide & Johnson, 1994), and is concerned with the kinds of explanations the researcher tries to develop. As such, this form of credibility asks how valid the data analysis is, and whether or not we can trust the interpretations that are based on such data. Both forms of credibility are, to some extent, interwoven, but they look at the research design from different directions (see Figure 5):

RESEARCH QUESTIONS → RESEARCH DESIGN ← EXPLANATIONS

Methodological Validity *Interpretive Validity*

Figure 5. Two forms of qualitative validity

To strengthen the methodological validity of this study, I triangulated data sources as well as data collection methods. The process of gathering data from multiple sources, through multiple methods, results in a richer description of research phenomena. For example, I obtained information from individual students, individual instructors, and a focus group of students. I employed interviews and demographic surveys. I collected information from textual sources, such as the written QL curriculum, and science textbooks. A thorough review of literature also provided information on national trends and supplied important background data on the nature of both QL and general education science courses.

I also employed various strategies to improve the interpretive validity of this research. I specified my assumptions at the start of the project, and tracked the steps in which I made my interpretations through annotations to transcripts and field notes. I searched for contradictory evidence (a technique recommended by Lincoln & Guba, 1985), and relied on colleagues to conduct peer review of my coding scheme. I looked for variations in how I might make sense of the study data, and noted specific instances that challenged my expectations or emergent findings. Finally, I reviewed and discussed my findings with professional colleagues, seeking their insights as to ways we might best portray the reality of the situation.

Dependability

In a quantitative study, I would discuss measures taken to ensure the reliability of the findings. That is, the extent to which the findings can be replicated by other researchers under similar conditions. In this qualitative study, the research sample simply does not include sufficient numbers of subjects or experiences to provide a realistic degree of reliability. Lincoln and Guba (1985) argue that a more important question for qualitative researchers is whether the findings are consistent and dependable in relation to the data collected. I interpreted this to mean that the goals of qualitative research are not necessarily to eliminate inconsistencies or control for uncertainty. Instead, high-quality research in a qualitative tradition demands that the researcher document how procedures, coding schemes, and other tools of data analysis have been used consistently.

I established inter-rater reliability (Miles & Huberman, 1994) by asking colleagues to code several samples of interview transcriptions. Coding was generally consistent across these samples (approx. 85%). There were some instances in which the raters made inferences that I did not see supported in the data. In such cases, I reviewed the data more thoroughly, and we attempted to reconcile our differences in interpretation. In a few cases where reconciliation did not occur, I report the common aspects of the two counts (e.g. when one coder assigned five mathematical/statistical codes to a particular task, and another coder only assigned four of those codes, I counted the four codes they shared in common). I maintained an in-depth audit trail (Cresswell & Miller, 2000) in which I chronicled my rationale for the major decisions made during the research process. The purpose of this audit trail was to provide some degree of transparency to the research methods, and the trail consisted of journaling, as well as a system of research memos that detailed how the data was analyzed and interpreted. Finally, I kept a record of changes to the coding scheme (see Appendix D) along with the rationale for expanding or collapsing coding categories.

Confirmability

In many traditions of qualitative research, confirmability relates to the quantitative notion of objectivity. That is, the extent to which the findings are the result of research as opposed to researcher bias. The nature of this study makes pure objectivity impossible. Nevertheless, it is incumbent on the researcher to illustrate how the actual data can be traced to its origins–such origins hopefully being outside the mind of the researcher. Toward this end, a popular method in qualitative research is the aforementioned audit trail (Creswell & Miller 2000), which exposes the decision-making process to public scrutiny. In addition, I have tried to be forthright with the reader with respect to my own researcher biases. I have attempted to do this by documenting my own history with community colleges, with community college students, and with quantitative literacy curricula through a statement of researcher bias in the introduction to this study. Finally, I have attempted to remain reflexive throughout the inquiry, attending to and documenting the presence of the researcher and its effect on the phenomena under investigation.

Transferability

Generalizing results from sample to population is not the goal of this study. Instead, Lincoln & Guba (1985) stress the notion of transferability–the ways in which the *reader* determines the extent to which the phenomena that appear in this context can transfer to a different context. Patton (1990) describes this process as one of "context-bound extrapolations" (p. 491), in which the reader speculates on the likelihood that similar findings would also arise in other situations, under similar (but not identical) conditions. To help the reader make this decision, I provide thick, rich description (Geertz, 1973) of both the participants and the research context. It is through such descriptions that qualitative researcher have a claim that their results possess relevance in other contexts (Schram, 2003).

Furthermore, although the small sample size in this dissertation forbids empirical generalizations in the statistical sense, case study research does permit analytic generalization.

Analytic generalization is related to the discovery of "underlying and patterned dimensions to social life" (Karp, 2001, p. 278). Yin (2013) describes analytic generalization as a process of expanding and generalizing theories by comparing the results of a case study to previously developed theories. This is the type of generalization that I apply in Chapter Five, particularly when comparing the results of this study with Lobato and Seibert's (2002) theory of actor-oriented transfer, and to the word of Stein, Grover, and Henningsen (1996) on the implementation of academic tasks.

Limitations of the Study

I now turn to a brief discussion of certain limiting conditions in this study, some of which are common to most forms of qualitative research, and some of which are specific to the design of this particular study. I have attended carefully to these limitations, and considered several ways in which to minimize their impact.

In qualitative research, analysis is closely tied to the thinking and choices of the researcher. As such, qualitative studies are limited by researcher subjectivity. Researcher bias tends to flavor the study's underlying assumptions, the perceptions of the researcher, and the data that was deemed to be interesting and worthy of analysis. One key limitation of this study is the issue of subjectivity and potential for bias arising from the researcher's previous experiences as a community college student, community college instructor, high school science teacher, and QL curriculum designer.

A second limitation is what Maxwell (2012) refers to as *participant reactivity*. This is a phenomena connected with the interview process in which participants' responses are affected by the relationship between participants and interviewer. For example, in this study, none of the participants knew the researcher prior to their first interview, and this may have influenced their responses. They may have tried to help the researcher by giving answers they perceived the researcher was seeking. Alternatively, it is possible that speaking to a stranger caused participants to be more guarded or hesitant in their responses.

I took several measures to mitigate these limitations. First, I acknowledged my research agenda and stated my assumptions in the introduction to this dissertation. Professional colleagues, including community college professors, a fellow graduate student, and a small group of interested STEM-educators, analyzed my coding schemes. I de-identified all transcripts, removing personal names and markers, so as to reduce the likelihood of associating data with any particular individual. I continually reflected on the problem of participant reactivity, and made a conscious effort to create an environment that fostered open, honest dialog. My previous experiences conducting semi-structured interviews throughout my doctoral program became very helpful in establishing a positive environment.

Ongoing conversation between the researcher and participants during in-depth interviews allowed me to quickly confirm or modify my written field notes. Finally, all participants were invited and given two weeks to read and respond to their final case study report. All student participants took park in this opportunity, as well as four of the five instructors. This *member checking* (Glesne, 2011) unearthed small errors and minor inaccurate perceptions I had made, that I was able to correct in the final narratives presented here.

Piloting of the data collection instruments the semester before the main study allowed me to anticipate some of the questions that would be generated by the data, which in turn provided an opportunity to refine the data collection instruments. This enabled greater consistency in data collection for the main study.

In addition to limitations surrounding researcher bias and participant reactivity, this study was limited by the fact that the research sample was restricted. It should be noted that the student participants volunteered their assistance with the research project. It may well be that there are interesting characteristics shared by the students who did *not* participate that would yield conclusions other than those presented in this study. It is also conceivable that common characteristics of my participants may have led to a set of viewpoints that are not necessarily representative of quantitative literacy students in general science courses. A likely characteristic may be their level of interest in quantitative literacy; those interested in QL may have been more likely to respond to my initial calls for participants. Indeed, I strongly suspect that at least two student participants were motivated to do so because of their overwhelmingly positive experiences with the Quantway course itself, and a desire to talk about their experiences.

Therefore, one critique of this study might be that the results cannot be generalized to other students, or other community colleges. To this critique I would say that generalizability was not the goal of the study. Instead, I concentrated on *transferability* (Lincoln & Guba, 1985), through the use of thick description, detailed information about the research context, and background information about the study. Judgments of external validity therefore rest entirely with the reader of this dissertation. I have tried to enable the reader to evaluate possible connections between my research and the reader's own circumstances. This research does not make any claim to empirical generalizability, but instead presents a snapshot of the role QL instruction played in the general education science courses taken by participants at their particular community college.

This study was not intended to evaluate approaches to QL instruction being used in community colleges. Instead, this study may serve as a reference for mathematics or science departments to use when evaluating and revising their own programs. It may also raise questions within the collegiate mathematics community about the role of QL programs in preparing students for further academic study, which may in turn lead to further advances in the field of mathematics education. Finally, this study lays the groundwork for future research into the value of a QL course for non-STEM majors.

Summary

This chapter provided a description of the research methodology that framed this study. I employed a qualitative method known as comparative case study to advance our understanding of the connections students and instructors make between QL and general education science courses. The participant sample consisted of six community college students and five general science instructors. Multiple data collection methods were employed, including semi-structured interviews with students and instructors, focus group discussions with students, and document summaries. I examined the data in light of existing literature, and explored emerging themes in the data itself. I accounted for credibility and dependability through various strategies, including triangulation of sources and methods.

I conducted a literature review to establish a conceptual framework that influenced both the design and analysis of this study. Interpretations and conclusions drawn from study data were compared with existing literature, allowing recommendations to be made for QL instruction, science instruction, and further research. The intent of this study was to increase researchers' understanding of the role of QL in students' preparation for further academic study, particularly in the sciences. Additionally, I hope that the results of this research will be helpful for those involved with mathematics and science education in community colleges.

CHAPTER IV: PRESENTATION OF FINDINGS

Introduction

The purpose of this study was to explore with a group of community college students, and their science instructors, the quantitative literacy demands of general education science courses, and the ways in which students connect quantitative ideas across courses. Obtaining an understanding of this phenomenon would help mathematics educators better design quantitative literacy courses, and inform multi-disciplinary efforts between science and math educators. A major assumption underlying this study was the importance of attending to student and instructor reports of tasks in a general science course. Furthermore, by focusing on the ways in which students make connections across contexts (from a QL course to a science course), this study could inform efforts to improve both QL and science instruction. Finally, attending to the quantitative experiences of a group of students *after* they leave a QL course offers a unique way to describe the value added by taking a QL course in the first place.

In the previous chapter, I outlined the methodology employed in conducting this study. This chapter presents the key findings obtained from multiple interviews with six community college students and their five science instructors. The purpose of this chapter is to give the reader several specific findings that came out of these interviews. These findings are organized around the study's research questions:

1. Which mathematical/statistical components of a specific QL course (Quantway) do students report in tasks from subsequent general education science courses?
2. Which mathematical/statistical components of a specific QL course (Quantway) are to be found in instructor descriptions of tasks in general education science courses?

3. What levels of QL-demand characterize student descriptions of tasks in subsequent general education science courses?

4. What levels of QL-demand characterize instructor descriptions of tasks in general education science courses?

In this chapter, I largely refrain from drawing many conclusions or offering specific interpretations of the findings. Except for where an explanation is necessary for making sense of a finding, I have chosen to leave these interpretive aspects for the following chapter. I do, however, attempt to draw the reader's attention to several salient points that I will synthesize in chapter five. I provide the reader with summary statistics and carefully selected quotes from the study participants. These quotes represent an attempt at thick description (Denzin, 2001; Geertz, 1973) of the study phenomena by documenting a broad range of student and instructor responses. The purposes of this description are to allow the reader to experience the context of this study, and begin to understand reality as portrayed by study participants. The emphasis in what follows is to let the participants speak for themselves. The data used to support these findings are rich and complex, as illustrated by the quotations taken from interview transcripts. These illustrative quotations give some sense of the multiple perspectives brought to bear by study participants. Where appropriate, field notes and diagrams are included with the interview data to supplement the discussion. The primary topic of conversation throughout all the in-depth interviews was a set of science tasks as described by both students and instructors. The reader may wish to refer to Appendix A for a full summary of these task descriptions.

Five major findings emerged from this study. Findings 1 through 4 address the original research questions. Finding 5 arose through detailed analysis of study data, and provides additional insight related to the purpose of the study. The reader will recall that the interviews were coded by *task*, through a process described in chapter three. Altogether, the five general science instructors described 54 tasks, and the six student participants reported a total of 61 tasks (across 12 individual interviews and a focus-group). I coded these task descriptions for both mathematical/statistical components, and for QL-demand levels (Frith & Prince, 2009). I also tracked qualitative differences in the ways students and instructors talked about the same tasks, and the different ways in which students made connections between tasks in a general science course, and previous tasks in their QL course (Quantway).

1. Of the five broad categories of mathematical/statistical components in a QL course, students reported that *Data representation and analysis* appeared in their general education science courses more than any other component. The other components, in order of frequency reported by students throughout their general science course are: *Basic numeracy, Algebraic reasoning, Spatial/Geometric reasoning;* and *Reasoning about chance and uncertainty.*
2. Of the five broad categories of mathematical/statistical components in a QL course, science instructors also reported that *Data representation and analysis* appeared in their general education science courses more than any other component. The other components, in order of frequency reported by instructors throughout their general science course are: *Algebraic reasoning, Basic numeracy, Spatial/Geometric reasoning,* and *Reasoning about chance and uncertainty.*
3. Student reports of general education science tasks featured multiple levels of quantitative literacy demand. Analyzed in terms of the *highest* level a task requires, *Deriving Meaning* appeared more frequently (36.0%) than any other. *Applying Mathematical Techniques* was the highest level in 29.5% of student task reports. *Higher Order Thinking*

was the highest level in 16.5% of task reports, *Identifying and Distinguishing* was the highest level in 11.5% of task reports, and *Knowing* was the highest level in 6.5% of task reports.

4. Science instructor reports of general education science tasks featured multiple levels of quantitative literacy demand. Analyzed in terms of the *highest level* required by a task, *Deriving Meaning* appeared more frequently (35.2%) than any other. *Applying Mathematical Techniques* was the highest level in 29.6% of instructor task reports. *Identifying and Distinguishing* was the highest level in 18.5% of task reports, *Knowing* was the highest level in 11.1% of task reports, and *Higher Order Thinking* was the highest level in 5.6% of task reports.
5. Students were often (21/38 times = 55%) able to make a connection between tasks in their general education science courses and tasks from their QL course (Quantway) when *prompted* to do so by the researcher. They were occasionally (7/38 = 18%) able to do so *spontaneously*, they occasionally made *incorrect* connections (3/38 = 8%), and occasionally made *no connection*, even with prompting (7/38 = 18%).

Following is a full presentation of these findings, including data to support and enrich them. I present several quotes that are illustrative of each finding, the purpose of which is to (a) illustrate the perceptions and experiences of a group of people (whether students or instructors) and (b) to indicate the existence of patterns within the data. The quotes provide evidence for the assertions I will make in the following chapter, and also provide examples of the human experiences that lie behind the summary statistics.

Mathematical/statistical QL Components in Student Task Reports

A major goal of this research was to determine the extent to which community college students could recognize components from their quantitative literacy course in the context of general science courses, and what those components might be. In this study, I took an approach that views QL along two dimensions–one being mathematical/statistical components, and the other being types of thinking and reasoning. Finding one speaks to the mathematical/statistical dimension. During the interviews, students were presented with various tasks from their QL course, and asked to think of specific tasks from their general science courses that they thought shared any similarities. When necessary, the interviewer prompted the student by suggesting science tasks that had come up in interviews with the students' science instructors. The interviews gave the students an opportunity to describe science tasks, and to consider the extent to which science tasks were connected to tasks from a QL course.

Students described tasks from five separate general education science courses, and these tasks contained many mathematical/statistical components. Overall, students reported more tasks involving data analysis and representation than any other category of mathematical or statistical components. Students also reported many instances in which they had to perform basic numerical operations, and employ algebraic reasoning. Spatial reasoning tasks were reported with slightly less frequency, and tasks that involved reasoning about chance and uncertainty were occasionally reported (See Table 6).

Table 6.

QL components in general education science tasks (Student reports)

Name (# of tasks)	Data representation and analysis	Basic numeracy	Algebraic Reasoning	Spatial Reasoning	Reasoning about chance and uncertainty
Carol (14)	9/14	8/14	5/14	4/14	2/14
Gary (10)	6/10	6/10	5/10	3/10	0/10
Kelsey (6)	4/6	2/6	3/6	1/6	0/6
Erica (12)	6/12	4/12	5/12	2/12	1/12
Daliah (6)	3/6	2/6	2/6	2/6	1/6
Heather (13)	6/13	5/13	4/13	5/13	3/13
Total: (N = 61)	34/61 (56%)	27/61 (44%)	24/61 (39%)	17/61 (28%)	7/61 (11%)

Note: The parenthetical counts represent the total number of tasks reported by each student. Many tasks were coded as including multiple QL components.

Data Analysis and Representation

Student descriptions of science tasks often included direct references to visual displays of data. Carol indicated that such displays occasionally required her to consider multiple ideas at once:

> I think that was something we really concentrated on in [Geology], was how to interpret a graph, and the information that a graphs gives. Does it make sense? Like this chart [Figure 6] has two different scales on the vertical axis. One is pressure and one is depth. And we were looking at all three. Kilobars, it's matching. So if we knew two out of three we could estimate the other one. (Carol)

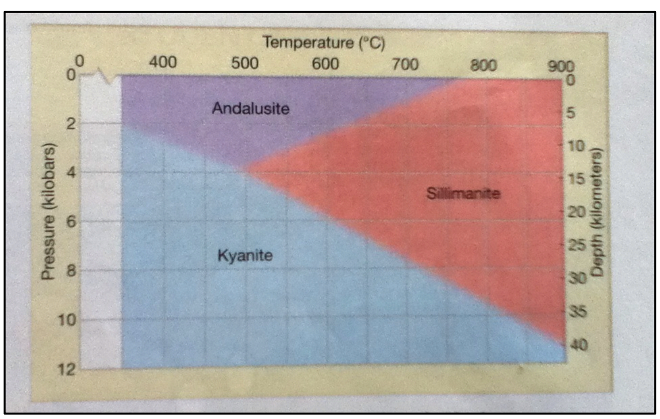


Figure 6. Temperature, pressure and depth of geologic formations (Busch & Tasa, 2014, p. 173)

Students frequently referred back to a QL experience when explaining how they learned to interpret such graphs. For example, Kelsey described a connection between a muscle contraction task and a previous experience in Quantway:

> This really struck me as something that made sense because of what we did in Quantway. Just being able to look at this [Figure 7] and being able to make sense of it you know as tension goes up and time goes like this, this is a muscle contraction. I feel like I'm – can do that better because of Quantway. The maximal stimuli– this is what that looks like, so it's making sense of the vocabulary, and what it looks like on a chart or a graph. If I was to get one of these terms, and this was a graph and it wasn't labeled, and you had to circle where the, the maximal stimuli is, you know, you'd have to make sense of what that is on a graph. (Kelsey)

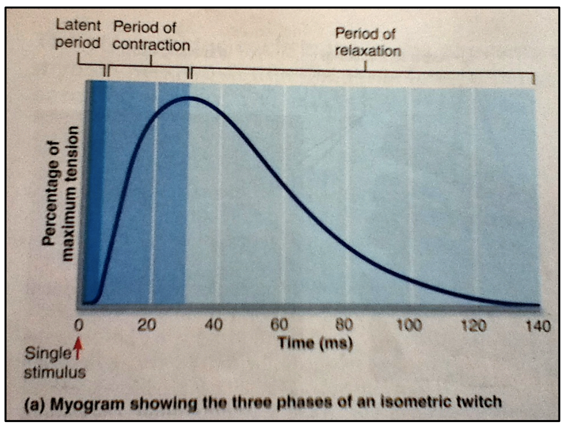


Figure 7. Muscle twitch response (Marieb & Hoehn, 2012, p. 294)

It often happened that a student would not recall the details of a science task with perfect clarity, but still attempted to describe the task in the interview. On occasion, a student would come up with a task from their science course that they felt had some connection to a graph they had seen in Quantway. For example, I gave Gary a Quantway task involving lines with negative slopes, and he described learning about main sequence stars in his astronomy class:

> Actually I recall us doing like, she [Astronomy Instructor] drew a graph that shows how light bends. She drew a line, like an axis, and then the line will curve down. There is a graph for that. [Figure 8]…The more hot ones were like, the blue, the bigger ones at the top. They are the hottest, and the cooler ones were down here. Hard to explain. [Drawing]. Like here are the white dwarfs, how they fell on that graph. So one axis is temperature, and the other I believe size. If I'm not

mistaken. I definitely know the bigger it is, pretty much the hotter. (Gary)

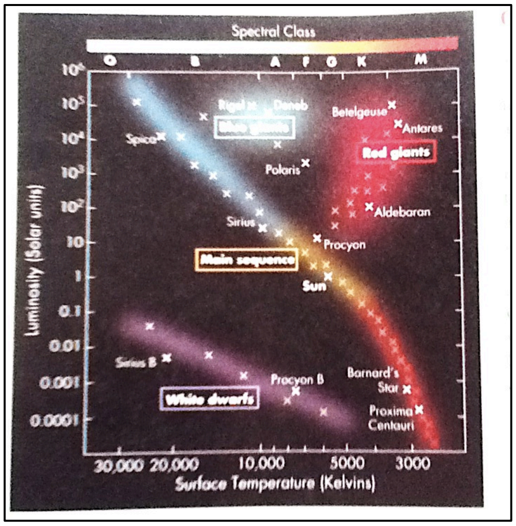


Figure 8. Main sequence of stars. (Arny & Schneider, 2013, p. 360)

Exactly how Gary viewed this graph as similar to the Quantway graph is not altogether clear, but this relates to a discussion on the different ways that students made connections that appears in a later section.

Basic Numeracy

All six of the student participants described multiple science tasks involving basic numeracy. This QL category includes performing basic arithmetic, converting between units of measurement, and making sense of numbers at different orders of magnitude. Often, science tasks involved multiple aspects of basic numeracy, as can be seen in Erica's description of a task involving the force of gravity between two bodies. Erica also seemed to recognized that the way in which she reported an answer often depended on the accuracy of numbers in the problem.

> There's an equation for the force of gravity between two planets. Or a planet and a star, I guess? But we didn't really have to remember the formula. We just had to plug things in and do the math. So like multiplying these numbers, then this number raised to some power, then dividing that answer–boom. Now, then again, something we discussed a lot was, how precise can the answer be? And that was also something from Quantway I remember. Rounding, I guess. Like, the speed of light. How precise do we want to be? Nine decimals? No, it depends on the other units in the problem (Erica).

Another aspect of basic numeracy that appears in many Quantway lessons, and which featured prominently in student reports of science tasks was working with percentages. When I gave Heather a task involving absolute versus relative percent change, and after some prompting, she offered a science task involving absolute versus relative humidity:

> We did a problem with relative humidity and absolute. Relative is the, oh, how close the air is to being saturated with water. So if you know the absolute humidity. No. If you know the, the capacity of the air, you just divide by the amount of water in the air, and multiply by 100 to get the percent. Or maybe the other way, I think. (Heather)

A Quantway task on percent of the U.S. federal budget devoted to different categories led Daliah, after some prompting, to give a description of percents in her cellular biology class:

> When we had to do basic metabolic rate, so that's like the minimum number of calories you need every day. Just to stay alive, I think. He made us do one about the calories we eat. And we had to keep track of what we ate, and how many calories we ate. And had to figure out how many calories were in the different nutrients, and so what percent of our calories are coming from fat? What percent are coming from proteins? I actually thought it was a good project, because you don't usually think about what percent of your calories are coming from different things. (Daliah)

Occasionally, students described a science task that involved multiple mathematical/statistical categories, such as basic numeracy and data analysis/representation. One example appears in this exchange between the interviewer and Carol, in which she described both using a table of data, and also understanding the role of percents in a task:

Carol: We looked at another chart, and the sill has crystals with this percentage of U, U-
IN: Like carbon dating?
Carol: Yes. We just did multiplication. Not too hard.
IN: So how does carbon dating work? I mean, what did you have to do?
Carol: Ah, so I think, I don't, well we can just look at it. So like this [lab sheet]. If you have this percent of the parent atoms, then you know how many half-lives you've got. And then it's just multiplication.
IN: Oh nice, so like percents and multiplication in two steps.
Carol: Sort of, but we didn't actually figure out the percents. We basically just had to take the percent and multiply.

In the above exchange, Carol specified exactly what this science task required her to *do*. For example, she stated that she did not actually have to do any calculations or conversions them before turning to a chart to determine the number of half-lives (and thus the age) of certain crystals. Most students were not naturally this specific about the demands of science tasks, which meant that I often had to press them to clarify what the task required, as opposed to giving a broad description.

Algebraic Reasoning

Variables, covariance, slopes, algebraic relationships, and other expressions of symbolic relationships were a frequent feature in student reports. Tasks reports featured a mix of formal expressions and manipulations and informal reasoning about relationships between changing quantities.

Gary provided an example of a science task involving inverse variation, noting how this kind of thinking was important in astronomy when considering the relationship between the apparent brightness of a star and its distance from the observer. Note that Gary also remembered that the relationship is non-linear, and was able to connect this task with a former experience in his QL course:

> Brightness, distance, and, oh actual brightness…yeah luminosity. There's a relationship and so if you have two stars with the same…luminosity, and one is twice as far away from you as the other…which one looks brighter? And is it twice as bright as the far one? Actually, it's not that easy. But we figured it out. So its not linear, and we had done some of that in [Quantway instructor's] class (Gary)

Heather spoke of an example of inverse variation from her geography course, and noted that she had previously worked with non-linear relationships in Quantway:

> So like I'm thinking of the percent of air pressure…there's like 30% of the air pressure at the top of Mt. Everest as there is at sea level. And at sea level there's

100%. So as you increase altitude, the percent of air pressure goes down… And I don't know what the rate is exactly. It might have been, well, I think it curved. But we did curves like that in Quantway, too. (Heather)

Most student task descriptions featured this kind of informal language with respect to algebraic reasoning. Statements in which students referred to specific formulas or variables were somewhat rare (of the 24 task descriptions that featured algebraic reasoning only 6 were coded as *construct or use equations in one or more variables*). Erica's description of the universal gravitation task (see above) was one example in which a student drew my attention to the use of formal variables. The formula to which Erica referred is:

$$F = G\frac{m_1 m_2}{r^2} \quad \textit{where} \;\; G = 6.67 \times 10^{-11} \frac{m^3}{kg \cdot s^2}$$

After Erica described the task, noting that it mainly required her to plug numbers into a formula, she admitted to struggling with the manipulation of variables, laughing, *"I mean, what is that* k *though? Do I multiply it by* g*?"*

Curiously, students occasionally described tasks that could have featured formal algebraic reasoning, but which the instructor appeared to modify so as to eliminate variables. Carol's description of a task involving density and continents is telling:

Carol: Okay, so yes we did talk about that [isostacy] a little. I mean, I guess it's cool that continents are basically floating on the Earth. Like an iceberg, you know?
IN: And you used a formula –
Carol: Right, well, there is a formula for density, I think? I don't really remember–
IN: Is this familiar? [Writing $P = \rho g h$]
Carol: No –
IN: This is pressure, this is gravity –
Carol: Oh, yeah we did do that. It didn't look like what you wrote. Just words.
IN: Words?
Carol: Like she would write out the words "density", "gravity", whatever. On both sides of the equation.

I took from this description that the instructor had elected to give Carol a formula involving density without resorting to the symbolic forms. I suspected that the reason for such an action was due in part to the instructor's perception that her students were not prepared to deal with formal symbolism in geology, and I elaborate further on this theme in the next chapter.

Spatial/Geometric Reasoning

Student task reports featured spatial reasoning several times throughout the interviews and focus group, including references to the geometry of shapes, and also to such things as scale factors on maps and diagrams. Some science tasks required students to consider how two quantities were related in terms of area or volume. For example, Carol described a task in which the class had to represent the layers of the Earth's interior as a cross-section of a basketball:

> We had this one problem where we took a basketball and pretended it was the Earth. And had to find the size of the different layers, you know? So if the inner core is…this big in reality, then it's like 2 centimeters on the basketball. The diameter, I mean. And so the outer core is this big, how big is it…on the basketball? And again, that was something we did in Quantway, scaling something down. Yeah. (Carol)

Scaling was a frequent feature of student descriptions, and Heather reported multiple tasks involving this component throughout her geography course:

> In a lot of the maps, you have to consider the scale. Like, are we looking at the whole United States? Or just a region? Or maybe one state or even a township. And the scales can be large or small. So maybe one map has a scale of, oh I don't know, 1 inch equals a thousand miles. And another might be one inch equals 10 miles. Just depends on the purpose. How much detail you need (Heather).

Spatial reasoning was not restricted to the physical sciences, as evidenced by Daliah's description of the importance of attending to scale on diagrams and images of the cell:

> It was, we had to know how magnified a picture was that we were looking at. Like, is that zoomed in 10 times? 40 times? 100 times? I mean, if two pictures in the book, side by side, and they looked the same size. But one is actually 100 times bigger than the other. And when we used the different lenses on the microscopes, you could figure out how many times zoomed something was. And what that meant, really. (Daliah)

Given the relative lack of attention to geometric reasoning in many discussion of QL (as discussed in chapter two), it is important to note that over one-quarter of all student task-descriptions featured some form of geometric reasoning. Although this may have been a result of the particular sample used in this dissertation, the role of geometric reasoning in QL courses aimed at preparing students for further academic study warrants additional discussion.

Reasoning About Chance and Uncertainty

Students provided descriptions of multiple opportunities to engage in thinking about uncertainty and chance throughout their general education science courses. Reasoning about chance and probability was often informal (for example, no student reported a need to apply Bayes' Theorem). A typical instance of probabilistic reasoning is found Carol's description of a phenomenon known as the hundred-year flood:

> It's…how big the flood is. We're supposed to get one that big every hundred years. And a thirty-year flood would happen every…thirty years. Well you're supposed to get one that often…but that doesn't mean you couldn't get two. But we didn't really get into any calculations. Just thinking about the meaning of the term, and how it is just a probability (Carol).

In response to seeing a Quantway task in which three lines were plotted on one graph, Heather made a connection to a task involving global warming predictions:

> Yes, I remember seeing graphs like that. Like when we talked about global warming. So there are different predictions, and I guess no one can know for sure. But like, best case, worst case, or whatever. And, oh, I don't remember it all. But I know that there are different predictions, and I think she said the different chances of them coming true. (Heather)

This was one of many instances in which I was inquiring about one QL component (data analysis and representation) and the student made a connection to a task involving a different component (reasoning about chance and uncertainty).

Summary

Overall, this finding suggests several interesting avenues of interpretation that I will describe more fully in the next chapter. It seems clear that of the broad mathematical/statistical components present in the students' QL course, *Data representation and analysis* featured most prominently in student task-descriptions across different general science courses. Students made several statements that suggest that they connected specific tasks in a science course with specific tasks in a previous QL course. They also suggest that certain mathematical ideas, such as algebraic reasoning, are treated with caution in general education science courses. Student descriptions, however, tell only one side of the story. There were interesting qualitative differences in the ways these students' science instructors described many of the same tasks, which leads us to consider finding two:

Mathematical/statistical QL Components in Instructor Task Reports

Of the five broad categories of mathematical/statistical components in a QL course, science instructors also reported that *data representation and analysis* appeared in their general education science courses more than any other component. The other components, in order of frequency reported by instructors throughout their general science course are: Algebraic reasoning, Basic numeracy, Spatial/Geometric reasoning, and Reasoning about chance and uncertainty.

A second goal of this study was to understand the aspects of a quantitative literacy course that science instructors emphasize in general education science courses. The instructors in this study had very little previous knowledge of the content of Quantway, but they were able to speak at length about specific science tasks that they perceived to be connected to quantitative literacy.

It is perhaps not surprising that there is an overlap between the QL components reported by students, and those reported by their science instructors, since in both cases the student and instructor were describing the same course.

Instructors reported that the ability to read, interpret, and make decisions based on visual displays of data was important for success in their courses. They also described many tasks in which students needed to employ algebraic reasoning. Multiple instructors described spatial reasoning tasks, as well as the need for basic numeracy. Tasks involving chance and uncertainty were reported occasionally (Table 7).

Table 7.

QL components in general education science tasks (Instructor reports)

Name (# of tasks)	Data representation and analysis	Algebraic reasoning	Basic numeracy	Spatial reasoning	Reasoning about chance and uncertainty
Prof. Geol (11)	9/11	5/11	4/11	4/11	2/11
Prof. Astro (13)	6/13	6/10	3/10	2/10	1/13
Prof. Physio (7)	5/7	5/7	4/7	3/7	0/7
Prof. Geog (12)	8/12	5/12	7/12	5/12	3/12
Prof. Cell (11)	5/11	6/11	7/11	3/11	4/11
Total: (N = 54)	33/54 (61%)	27/54 (50%)	25/54 (46%)	17/54 (31%)	10/54 (19%)

Note: The parenthetical counts represent the total number of tasks reported by each instructor. Many tasks were coded as including multiple QL components.

Data Analysis and Representation

Professor Astro described several tasks in which her students had to interpret information presented in graphical form. In the following description, she also noted that her students usually lacked the skills needed to make sense of such graphs. This tendency to describe student skills in terms of deficits is a common theme among instructor reports, and one that I will probe more deeply in the next chapter.

The graph version of this [Figure 9], and you have your intensity and your peak

> wavelength. You have the independent variable. You have a shift like this versus this. Finding that peak, looking down here, it was lights out. They have no idea. They got none of it at all. This is really depressing. I don't have a single student this semester, perhaps in the past, who was able to interpret this. This is really where they get lost. (Prof. Astro)

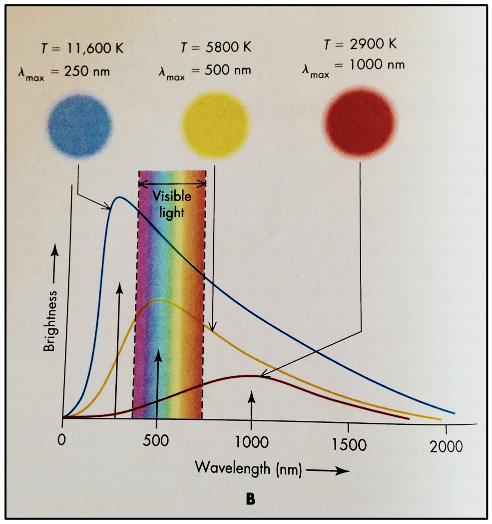


Figure 9. Wien's law (Arny & Schneider, 2013, p. 98)

Professor Geol described more tasks involving visual displays of data than any of the other instructors. For example, she reported that students in her geology course actually construct their own graphs based on real data:

> They have to look at the pictures of the charts, and I do make them go back and forth between different graphs. They're interpreting isolines…And like I said, a lot of looking at data and plotting it on a graph. There's one activity where they have to construct a graph of change in elevation based on isolines (Prof. Geol)

In geography, students are asked to interpret a graph that includes multiple projected scenarios. As mentioned earlier, this task also features an element of probabilistic reasoning:

> It's a potentially divisive topic, but we do get into climate change, and models for rising temperature. So this is one graph [Figure 10] where there are three predications–sort of a worst case, best case, and no change situation. And the ability to follow what's going on here, I have to spend a lot of time on this. Which line are we on now? How do we find the difference between these predictions 25 years from now? (Prof. Geog.)

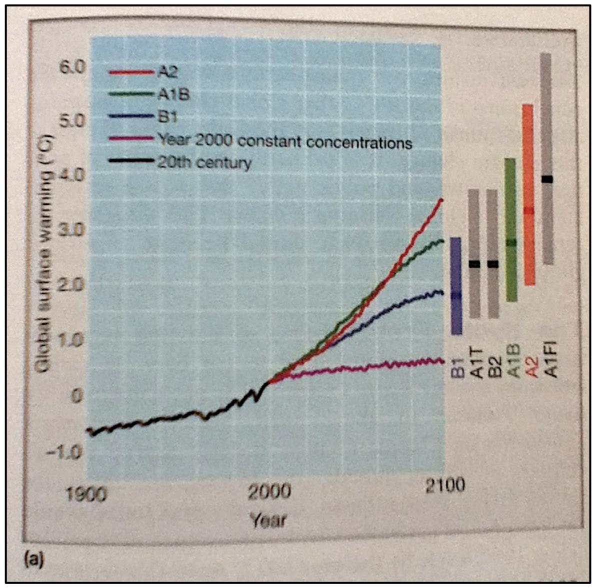


Figure 10. Three models of climate change. (Hess & Tasa, 2013, p. 229)

Even in a course such as cellular biology, which according to Professor Cell doesn't include "much statistics", students need to engage in data analysis:

> We do talk about mortality rate, so they're taking data off a table and using it to, well, understand mortality rates basically. I mean, these columns [Table 8], what we're trying to get them to see is that mortality rates are just a factor of the number of organisms still alive after a certain duration of time. (Professor Cell)

Table 8.

Life table of Dall Mountain sheep (OpenStax College, 2013).

Life Table of Dall Mountain Sheep

A	B	C	D	E
Age interval (years)	Number dying in age interval out of 1000 born	Number surviving at beginning of age interval out of 1000 born	Mortality rate per 1000 alive at beginning of age interval	Life expectancy or mean lifetime remaining to those attaining age interval
0–0.5	54	1000	54.0	7.06
0.5–1	145	946	153.3	—
1–2	12	801	15.0	7.7
2–3	13	789	16.5	6.8
3–4	12	776	15.5	5.9
4–5	30	764	39.3	5.0
5–6	46	734	62.7	4.2
6–7	48	688	69.8	3.4
7–8	69	640	107.8	2.6
8–9	132	571	231.2	1.9
9–10	187	439	426.0	1.3
10–11	156	252	619.0	0.9
11–12	90	96	937.5	0.6
12–13	3	6	500.0	1.2
13–14	3	3	1000	0.7

Through the use of tables, graphs, charts, and diagrams, all the science instructors in this study reported that they convey scientific ideas that require students to analyze and represent data. Task descriptions featured many instances in which students were asked to use data to think about how two or more scientific phenomena, such as brightness and wavelength, varied with respect to one another. The notion of covariation also plays an important role in algebraic reasoning with respect to science.

Algebraic Reasoning

Science instructors presented several examples of tasks in which students were asked to engage with either formal or informal algebraic reasoning. These descriptions point to a tenuous relationship between algebra and science instruction for non-STEM majors. One task from Introduction to Astronomy asks students to think about the meaning of an inverse relationship as represented by a formula:

> Yeah, we use Wien's Law which is the relationship temperature and wavelength. So it's as simple as, I'll just write it on here. [Writing $T = \frac{2.9 \times 10^6}{\lambda_{\max}}$]. And this, even this idea. This is simply saying that the hotter something is, we should expect a shorter wavelength. The cooler something is, the longer. To even explain this inverse is, wow. (Prof. Astro)

Professor Astro indicated that her students struggle to explain the inverse relationship represented by the formula. When I asked Erica about this task (see Finding 5 below) she also struggled to explain it. Students in Quantway have multiple opportunities to work with relationships such as this, in which increasing the value of one variable leads to a decrease in another. In particular, Quantway students explore several contexts in which they change the value of a denominator and note the result on the value of the entire term. All of the Quantway contexts, however, involve more every-day situations.

A particular task in Geology, involving glaciation, presented an opportunity for students to think about variation, with the science instructor specifically referring to the use of a variables. Note that this quote also reveals the instructor's perception that her students are unable to understand the role of variables in such a task:

> The plate movement, or glacial movement for example. How fast is the glacier receding? And then I'd do the equation of D over T and then I'd move it all around. And they'd all look at me like, "What?" But it's just a proportion, right? But they don't really understand the symbols so they struggle to get the big idea here. (Prof. Geol.)

Algebraic reasoning tasks were not limited to the physical sciences. Professor Cell explained to me how he pushes students to think about covariance between quantities in terms of diet, calories, and nutritional needs:

> I bring up the issue of nutrients, and the balance of that sort of thing. So if this were a really carb-heavy mean, what do you need to do to balance it out, and that sort of thing. I want them to talk about it in terms of proportions, and if the proportion of your daily calories coming from carbs goes up, then the proportion coming from other nutrients must go down. Or else increase your total calorie intake. And some students actually take that and straight away think, okay, if can eat x more carbs in this meal then I normally would, that translates into so many calories, and I have to sacrifice somewhere. (Professor Cell)

Basic Numeracy

Basic numeracy, including performing simple arithmetic, considering orders of magnitude, and working with percents, appeared in nearly one-half of all instructor task-descriptions. Professor Geog described her frustration with students who struggle to tell the difference between percent and cumulative percent:

> Here, this [Figure 11]…is the percent of a percent. The sea floor is shaded what color? Blue. Lowlands are shaded what color? Green, and the mountains are shaded. Can they read this? No. Do they get the point of cumulative percentage? No. Okay, now elevation. Highest percentage of Earth's surface, highest percentage not cumulative, percentage. What they are doing, I don't know if they are not reading the questions, or they aren't comprehending. Difference between percent of surface or cumulative percent of surface. And that's, most of them get

that wrong (Prof. Geog.)

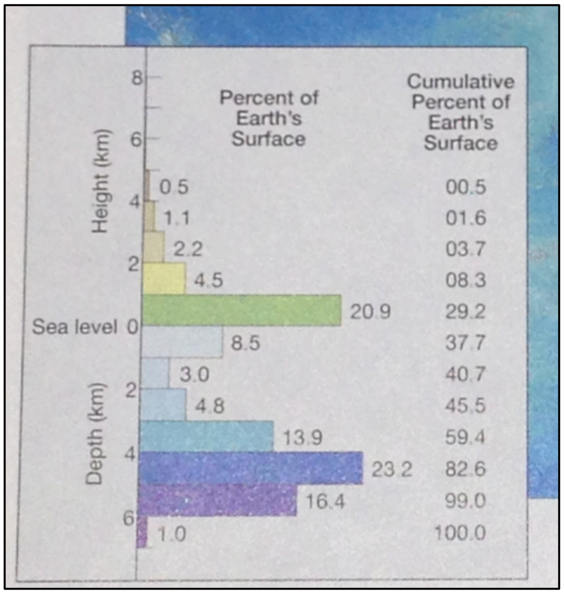


Figure 11. Histogram of global topography (Busch & Tasa, 2014, p. 19)

Professor Cell coupled his own remarks about the need for basic numeracy with a lament that his students neglected to attend to precision in their numerical answers:

> The equations that I give them–say the Harris Benedict equation–are usually a reliable estimator, and I tell them they have a margin of error of about 10%. And there's one I give them that has a decimal point in the wrong place, to see if they're following me, you know. So it makes a huge difference, and people were giving me these absurdly low numbers, but they didn't think anything about it! I had to bring it to their attention. You're off by an order of magnitude here, people. (Prof. Cell)

Spatial/Geometric Reasoning

Instructors from all five courses described tasks that involved spatial or geometric reasoning. For example, Geography students appear to do a lot of map work. In her description of one such task, Professor Geog described how attending to scale is important:

> They don't know how to think logically. We're talking about a location at 49 degrees North latitude. And I tell them, one degree off is about 69 miles. And I had one student who, instead of giving me Indianapolis gave me Cleveland. And another gave me South Bend. They don't really attend to the scale on a map like this. (Prof. Geog)

In his Human Anatomy and Physiology course, Professor Physio directs students' attention to the different shapes of muscles in the human body, and how the geometry of a muscle reflects its purpose:

> I mean, I don't know if this is what you're looking for, but when we study fascicle arrangements, we're basically studying the different shapes of muscles. Circular, convergent, parallel, pennate. And why they have those shapes. I mean, what kind of mechanical advantage are you getting based on shape? Or which arrangement would shorten the most in a contraction? (Prof. Physio)

Professor Cell described a task involving surface are to volume ratio, noting that it is a "crucial" concept in his course:

> In the same unit, we talk about scale, this comes up because the shape of cells is often related, and I get into this a lot, the surface area to volume ratio is crucial to understand. Basically, the more surface area you have, it is a clue that there is a going to be a lot of stuff happening at that spot. You have much less surface area if you are trying to conserve volume in terms of…usually water. So we talk about what is the optimal packing of cell and why are honeycombs hexagons and that sort of thing. (Prof. Cell)

At the risk of redundancy, it is notable that over one-quarter of task descriptions given by science instructors included an aspect of geometric or spatial reasoning.

Reasoning About Chance and Uncertainty

Instructors reported several opportunities for students to engage in probabilistic thinking. One aspect of this category that surfaced multiple times involved interpreting statements regarding conditional probabilities. Professor Geog noted her students' difficulty in grasping the notion of a 100-year flood, and described attempts she has made to help improve their understanding:

> The one that really messes them up is flood re-occurrence interval. Just because we had a 100-year flood doesn't mean we won't see those flood waters again for another 100 years. It's a probability, really. We haven't seen it in 100 years means what? We won't see it for another 100 years? No. And how to calculate it. What is a "100-year flood"? I go to YouTube. I try all kinds of different tools, methods, because everybody learns differently. (Prof. Geog)

Professor Cell also noted that he makes use of probability as it relates to genetics:

> Actually, there are some significant consequences related to probabilities, and one of the ones that I bring up has to do with eye color. Everyone thinks brown eyes, blue eyes, dominant, recessive, and that's the way we teach it. If you have two blue-eyed parents, you shouldn't have a brown-eyed child, and if you do, then somebody did something wrong. The question, "Who's my daddy?" comes up. Well, it's not that straightforward, and we work through the probabilities. In fact, there are a minimum of three sets of genes that control eye color, and what's more, even if you have the dominant alleles for brown eye color, they can get shut off through other things…and then they can pop up again in the next generation. So there is a certain probability that blue-eyes parents could have a brown-eyed kid without any hanky-panky. (Prof. Cell)

Summary

Finding two suggests that a major mathematical/statistical component featured in instructor reports of science tasks was *data analysis and representation*. It also suggests that a significant number of science tasks require basic numeracy and algebraic reasoning. Furthermore, the types of tasks found in these general education science courses feature a significant amount of geometric and spatial reasoning. Instructor reports tend to be critical of their own students' abilities to engage with the quantitative aspects of general science courses. I will elaborate on these themes in the next chapter. For now, let us consider the quantitative aspects of general science instruction from a different lens, levels of QL-demand.

Levels of QL-demand in Student Task Reports

Student reports of general education science tasks featured multiple levels of quantitative literacy demand. Analyzed in terms of the *highest* level a task requires, *Deriving Meaning* appeared more frequently (36.0%) than any other. *Applying Mathematical Techniques* was the highest level in 29.5% of student task reports. *Higher Order Thinking* was the highest level in 16.5% of task reports, *Identifying and Distinguishing* was the highest level in 11.5% of task reports, and *Knowing* was the highest level in 6.5% of task reports.

One of the assumptions behind this dissertation is that quantitative literacy cannot be reduced to a simple list of mathematical or statistical techniques. Although familiarity with certain techniques may a part of what it means for a person to be quantitatively literate, there are other dimensions to QL. One such dimension is the reasoning competencies required by a task. This dimension describes the range of knowledge, behaviors, and processes required to engage with a general education science task. In analyzing the study data, it was clear that a single task might make QL demands at multiple levels. The percentages reported above represent the *highest* level of QL demand reported by a student when describing a task. Thus it should not be taken that the QL-demand level *knowing* was required in only 6.5% of science tasks, but rather that 6.5% of tasks *only* required the kinds of reasoning characterized by *knowing*.

Furthermore, I do not mean that if a student task report featured characteristics of *higher order thinking*, that the student necessarily engaged with all the lower levels. Multiple examples occur in the data in which a student reported having to evaluate or reflect on a quantitative solution, without having to apply any particular mathematical techniques.

In this study, I did not take the approach that a science task inherently requires any quantitative competencies. To be sure, there are mathematical or statistical components that one would expect a student to employ during the course of a task (such as multiplication, or fitting a line to data). In terms of levels of QL-demand, however, I wish to be very careful not to specify that any task forces every participant to engage in the same cognitive demands. Research (Stein, Grover, & Henningsen 1996) indicates that the quantitative demand of a task depends largely on how the task is enacted in a classroom. Furthermore, following Lobato's (2006) actor-oriented ontology, it is perfectly possible that two participants (e.g. the student and the instructor) might describe the same task in terms of different levels of QL-demand. Therefore, in this analysis, I coded tasks according to what the participants *told* me they did, not according to what I could deduce from a textbook or lab sheet. The fact that a student (or an instructor) described the process of engaging in certain QL-demand levels throughout a task does not mean that the task itself inherently required those levels of thought. There is no objective prerequisite on thinking in tasks. Although I categorized task reports according to a conceptual framework, which required me to make certain inferences, I have tried to be straightforward in reporting what the participants described.

A few tasks, as described by students, only required knowing the meaning of quantitative terms or phrases, or the conventions for symbolizing numbers or variables in equations or on tables in graphs:

> We did talk about it…if a river enters a gorge, its flow constricts. So does it speed up, or slow down? So it speeds up, right? We didn't really do any calculations. Just that statement, and that was all she asked on the test. At which point in river the does the flow have greater velocity? (Carol)

> We did one worksheet about knowing the difference between speed and velocity…yes, speed is just how fast you're going. And velocity is like your speed plus…your direction. And displacement, which is like distance, but more like the difference between you're starting and ending points. So we had worksheet where we just had to know that. I mean, that was literally all. You had to know those terms. (Gary)

> She gave us a few problems, like a pre-test, and we had to know what scientific notation looks like. So whatever times ten to the whatever power. Like, was it the right form? And did you know the significant digits, but it was just multiple choice, you know? (Erica)

More frequently, students described tasks in which they had to engage in thinking that went beyond simple knowing. In such tasks, coded as requiring *identifying and distinguishing*, students reported a need to recognize distinctions between different representations, to identify the relevant information in a representation, or determine what mathematics needs to be done (but perhaps *not* carry out any actual computations). For example:

> We did talk about differences in the kinds of maps you can make. And she made a big deal about how hard it is to put a 3-D world onto a 2-D paper. So there's different projections. Like one looked like orange peels, and another like the normal map, and one was circular top down…yeah, there are advantages to each...but I don't really remember what they were. Just that idea that there are different ways to make maps of the world, but they're all showing the same thing differently (Heather)

> We did these discussion board assignments, and they were just things he wanted us to read. From magazines, or whatever. Some of it was really boring, to be honest! But he really wanted us to be able to read it and say, okay, what was important here, what was relevant, what was irrelevant. What was just [somebody's] opinion, and what was scientific fact? (Daliah)

Still more frequently, students described tasks in which they were asked to derive meaning from textual, graphical, or diagrammatic representations. This category also applies to tasks in which students had to translate between different representations of the same phenomena. For example, in Kelsey's description of the muscle contraction graphs, her report indicates that a student had to recognize that a diagram consists of multiple different kinds of representations, understand the implicit differences in scale between the diagrams, consider the relationships between the text in the caption of the diagram and the graphs in the diagram, and then derive meaning from the diagram as a whole.

> And, like I said, this is where I thought the stuff we did in Quantway was really helpful, because you're looking at a lot of things at once here. Three graphs of muscle contractions, you know? And here's a drawing of the contracting muscle. There's different units going on here, and then the caption helps you know what you're looking at. But what's the big picture here? And because we did a lot with graphs in Quantway, I wasn't, I didn't feel intimidated by this stuff. I knew where to look for things (Kelsey)

Erica provided an example of a task in which she had to derive meaning from a diagram and use it to help make sense of geometric (rotational) phenomena:

> My presentation was on Uranus, and so basically I just had to make a PowerPoint…but there were a lot of graphs. And I remember this one where I had to explain how the seasons are really weird because of its tilt [Figure 12]. I actually have it here. And I remember thinking this is so hard to understand at first, but then…she explained it some more to me. Basically it is so tilted that sometimes the sun will be up for, like, years. And then in other seasons it rises and sets almost like on Earth. It's weird. (Erica)

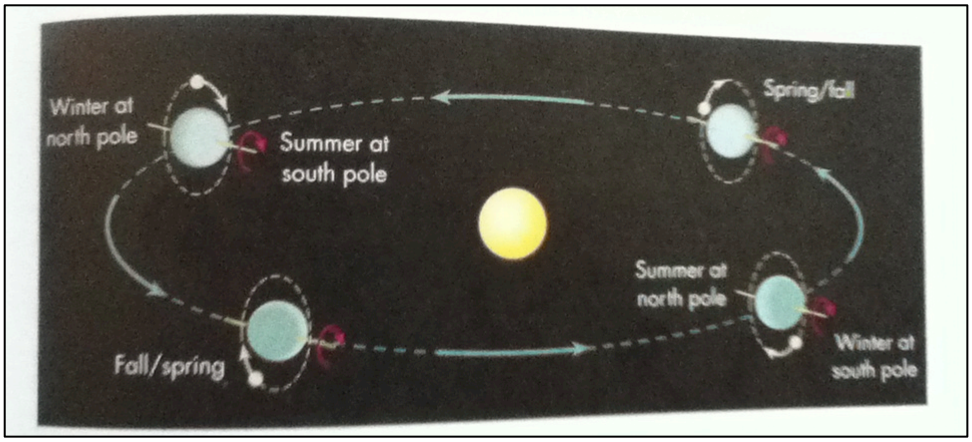


Figure 12. Orit of Uranus (Arny & Schneider, 2013, p. 275)

Students reported opportunities for applying mathematical techniques such as calculating, estimating, measuring, or applying algebraic or geometric techniques. For example:

> So we had to, that was early in the semester, so at one point America and Africa were one continent. And as time went by, the plates separated. So we had to say, how many years ago were the two points together? Or calculating the rate they moved…kilometers per year. Not per year. They don't move like that, so more like per million years. So this map is how it looks now, and as you go back in time, these points were closer. How long ago, knowing the current rate, were they together? (Carol)

> Figuring out gravity, there's this one problem. Like how much gravity is there at the space station, and it was like you had to consider the variation that the Earth, like the center of the Earth, to the top, the crust of the Earth, so you had to add that distance in. Into the distance between the Earth and the satellite. At first I didn't get why that was important. But like here, calculating the force of gravity, you have to use the circumference. Radius. Stuff like that. You need the distance between the centers of the objects. (Erica)

Finally, students reported some tasks that emphasized aspects of higher order thinking. In such tasks, the students reported opportunities to synthesize information from multiple sources, make conjectures, reflect, or evaluate. There were instances in which students reported having to engage with higher order thinking as a final step in a problem that also required all the lower levels of thought. But there were also instances in which higher order thinking was apparent, but a particular lower level (e.g. applying a mathematical technique) was not required. An example of the former instance came from Carol.

> In going from point A to A′, how much, what is your change in elevation? And you can't tell very well from this map [contour lines]. I mean, you know what the lines mean, but on the whole trip, did you go down, then up a bit, then down a lot, and then up a lot? She made us think, is that an easy hike? Because it starts and ends at the same elevation. How can you tell? But on this [graph of elevation vs. distance] it's easy to see. And this was a task that I really struggled with at first, because, well, I jut didn't know how to transfer these points [contour lines] onto this axis [elevation graph]. But then once I got the technique down, I understood. So we had to sit back and think, what is it about this display that is better? (Carol)

In Carol's description, she had to know the conventions for graphical representations, identify the mathematics to be done (transferring points between graphs), derive meaning from a graphical representation, measure, estimate, and construct, and finally reflect on and evaluate the final product. In the focus group, Heather described a task in which she engaged in higher order thinking, but it is less clear what specific mathematical technique she applied (if any).

> I think we really got into that kind of [higher order] thinking when we talked about global warming. Like, I remember when we had to look at these graphs of predictions, and in one the map of the Earth is colored red, and the other is more like a line graph. And this was something that, before Quantway, I think I would have just been like, woah graphs. That's scary, right? But I felt like, no, I can make sense of this, and even see that the graphs were both showing the same thing, and they actually help you think about–what's going to happen in the next twenty years or whatever. And why are there different predictions, anyway? (Heather)

Overall, Finding Three indicates that when these students describe the quantitative tasks in their general education science courses, the majority of task descriptions do not include aspects of *higher order thinking*. On the other hand, it appears from student reports that the majority of quantitative tasks do require them to engage with levels of QL-demand beyond mere *knowing*. Furthermore, student task reports included aspects of *higher order thinking* with more frequency than instructor task-descriptions. I discuss possible reasons for this result in the next chapter. To see how the different QL-demand levels appeared in *instructor* reports of science tasks, we now turn to Finding Four.

Levels of QL-demand in Instructor Task Reports

Science instructor reports of general education science tasks featured multiple levels of quantitative literacy demand. Analyzed in terms of the *highest* level required by a task, *Deriving Meaning* appeared more frequently (35.2%) than any other. *Applying Mathematical Techniques* was the highest level in 29.6% of instructor task reports. *Identifying and Distinguishing* was the highest level in 18.5% of task reports, *Knowing* was the highest level in 11.1% of task reports, and *Higher Order Thinking* was the highest level in only 5.6% of task reports.

As with finding three, I relied on human interpretation of tasks as the basis for determining the levels of QL-demand featured in each task. Therefore, I coded tasks based on the instructors' perceptions of what students would have to do to accomplish each task. Furthermore, just as with finding three, the above percentages represent the *highest* level of QL demand that could be found in an instructor's description of each task.

Professor Geol provided an example of tasks that, according to her description, only required students to know the meaning of quantitative terms and phrases:

> There is a lot of vocabulary that they need to know, sort of up front. What's the difference between volume and density? Do you know what those words even mean? And I try to get them to think in terms of different materials, pumice and whatnot. And say, these are the same volume, roughly. But one is so much heavier. So what is density? I don't even talk about a formula at that point, I just want them to have a conceptual understanding of the terms we're going to use. (Prof. Geol)

Professor Geog described a task in which students need to know the conventions for the symbolic representations of numbers:

> I give them a tutorial at the beginning of the year. And they just flat out aren't competent. What does it mean when I say, "sig figs"? No idea. "What's a whole number?" No. So I have to go over all these terms. Round to the nearest whole number. Do they get it? No. They also don't understand that if you type it into your calculator, there are no commas for large numbers. So they give me a large number, and I say, "read me that number", and they don't know. So I have to review all these conventions. (Prof. Geog)

Professor Cell described his experiences teaching students to distinguish between relevant and irrelevant information in a scientific article:

> From my perspective, it is something that, if they are reading about science in the news or a scientific study, how likely is it that they got the answer they got? But we can't really get into that very deeply. But we do talk about, in this article, can you separate scientific fact from opinion, from conjecture? I mean, I give them articles from the news, from journals, I try to make it interesting. But I want them to be able to point to the important information in an article. (Prof. Cell)

Professor Astro stated that the overwhelming majority of the tasks she uses in her course only ask students to engage with *knowing* and *identifying and distinguishing*:

> I wish I could do more of that [higher order thinking]. But honestly, most of what we do is in these two levels [Knowing; Identifying and Distinguishing]. I'd say 90%...But honestly, most of them can't even do that. It's really hard for them (Prof. Astro)

I found it remarkable that Professor Astro would make such a claim about tasks in a college-level science course, but at the time I had no way of knowing whether or not her assertion was true. After coding, it appears that of the 13 different tasks described by Professor Astro, 3 tasks (23%) required only the kinds of thinking characterized by the two lowest levels of the QL-demand framework. Of course, Professor Astro did not spend much time contemplating the QL-demand framework before making her claim, but her perception of the kind of thinking required for tasks in her class is important nonetheless. The reasons behind this perception, and the possible ways in which such a perception influenced the way tasks were used in her course, is one theme I pursue in the next chapter.

Tasks in which instructors expected that students needed to engage in *deriving meaning* included the isolines task described in the previous section, and this example from Professor Physio:

> I mean, take something like this, this idea of twitch response. I want them to be able to read this graph [Figure 13] and just be able to say, the response time is greater for a muscle in your calf than a muscle in your eye. Right? And you know that from experience, but this graph, I labor over this. Just tell me what's going on here. And they should be able to see that the three muscles each experiences the same level of tension. But one takes much longer to relax. (Prof. Physio)

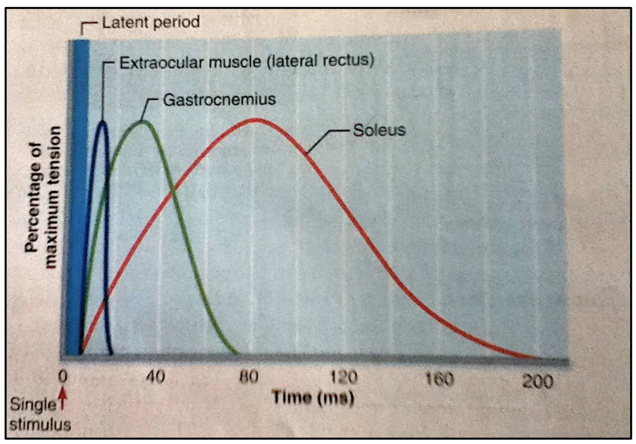


Figure 13. Difference in muscle twitch response times (Marieb & Hoehn, 2012, p. 294)

Instructors reported multiple tasks in which students had to apply mathematical techniques, such as calculating, estimating, measuring, or applying an algebraic or geometric technique.

Many examples of tasks in which students had to apply mathematical techniques featured domain-specific terminology. Terms such as *arc-seconds*, *BMI*, and *declination* appeared with much regularity, adding an additional level of complexity to the required mathematical procedures:

> I make them locate stars on the star maps that are in there. So the measurement is in degrees, but they need to know how to get increments of degrees. We talk about increments of 360, you know a degree is about this, so if we shift that way, minutes, arc-seconds. They need to be able to make those calculations. (Prof. Astro)

> One of the things that struck me a few years ago as being rather funny, and so I've kept this example in my classes, is if you do my BMI I am at the high end of obese. Barry Sanders is my exact height and weight. And those are the only two pieces of data that go into that. But the students calculate the BMI, and there is no way Barry Sanders is obese. So BMI is a really lousy statistics to use for yourself. It is good for populations, but not individually (Prof. Cell).

> One problem they have to do dealing with maps is, you have different years of the same map. And you have magnetic declination changes. Since it is moving. Eventually we're going to be flipped upside down. So they have to calculate the difference in the magnetic declination. I even give them a hint here. Put it into minutes and then calculate so it's like 1.5 degrees, and put that into 90 minutes. And the other one is three degrees, 25 minutes. Put that into minutes. Then subtract, and then you re-convert back into degrees and minutes. Can't do it….different base systems. It's not in base ten. (Prof. Geol)

Finally, instructors reported a few opportunities for students to engage in higher-order thinking. In one task, described by Professor Astro, students are asked to make logical conjectures that synthesize facts about temperature, gravity, and the solar system:

> Like for instance, in one class we spend a good amount of time pursuing some hypothetical questions. And I said, if the sun were a little hotter, what would happen? And it was 15 minutes of, well, it would be bluer. And what else would happen? We would get hotter. And what else? Mercury would be in trouble. And what else? So we're drawing out all these things. Let's conjecture, like you said. Think about this logically. Or another one I like to use is, what would happen if the Earth were bigger? Or if it were spinning faster? Just some fun questions like that. (Prof. Astro)

Overall, finding four indicates that when science instructors describe the quantitative tasks in their general education science courses, the majority of tasks do not require much *higher order thinking*. In fact, the instructor reports contained even less of what might be considered higher-order thinking than task-descriptions from their students. Furthermore, instructor comments indicate that they are aware of the lack of higher-order thinking tasks in their courses. At least one professor perceived the vast majority of science tasks in her course as only requiring the two lowest levels of QL-demand. Finally, instructor descriptions of tasks frequently relied on terms that are specific to their individual disciplines.

Before closing this chapter, I wish to present a finding that was not originally a target of the study's research questions. This finding arose as a direct result of the data analysis methods I employed, notably the search for themes within and across semi-structured interview data. The reader will recall that my primary method for eliciting student descriptions of QL in their science courses was to first remind them of specific tasks from their Quantway course. Usually, students spent some time recalling the Quantway task, and would often give me additional details about how it was implemented. Once a student indicated some degree of familiarity with the Quantway task, I would ask students whether or not they could think of a science task that contained similar QL components (see Appendices D and E).

As I studied the transcripts of individual student interviews, a certain pattern became clear: The students were indeed making connections between tasks in their science courses and tasks in a QL course, and the conditions under which they made these connections generally fell into four distinct categories. These distinctions are summarized in Finding Five.

Types of Connections Made by Students

Students were often (21/38 times = 55%) able to make a connection between tasks in their general education science courses and tasks from their QL course (Quantway) when *prompted* to do so by the researcher. They were occasionally (7/38 = 18%) able to do so *spontaneously*, they occasionally made *incorrect* connections (3/38 = 8%), and occasionally made *no connection*, even with prompting (7/38 = 18%).

One finding to arise out of the data analysis process itself was that students made connections between tasks in their general education science courses and tasks in Quantway under qualitatively different circumstances. In coding transcripts, I realized that I often had to prompt a student with a specific science task (provided ahead of time by instructors) before they would begin to describe any connections between the science tasks and the Quantway task. On other occasions, students seemed able to describe such connections without a specific task prompt. Upon further review of the transcripts, I discovered instances in which the students did not make a connection at all, even after I prompted them with the specific science task. And finally, there were a few instances in which a student tried to connect two tasks in ways that were inappropriate from a mathematical standpoint.

Over the course of all the interviews, students described 61 different science tasks, but the way in which these tasks came up during the interviews differed. Sometimes students initiated conversation about a task. Kelsey, for example, arrived at her second interview with a folder full of handouts she had collected from her science course, and began the interview by excitedly describing each task. At other times, a student would bring up a science task near the end of an interview, and I was unable to tell which (if any) task from Quantway had prompted their thinking. In other instances, a student would describe one science task, and then immediately follow up with a description of a different task.

Therefore, Finding Five specifically deals with the category of student descriptions that began with the researcher describing a specific task from Quantway. Overall, this type of interaction occurred 38 times. That is, on 38 occasions, I described a specific task from Quantway, and noted how the student responded. This finding does not directly address any of the major research questions guiding this study, but does have a bearing on the forthcoming discussion and synthesis of the study findings.

What follows is an example of an interchange in which the student made a spontaneous connection between a QL task and a task in her general education science course. I had just reminded Carol of Quantway task involving the federal budget, percents of the whole, and percents of portions of the whole budget.

Carol: So basically all the math that's been in Geology has been a review for me- it basically has just been basic arithmetic and some percentages. There's been, oh! The last couple chapters we were talking about percentages of percentages.
IN: Yes?
Carol: Which, if I hadn't done all the things in QW about percentages, and percentage points and all those different things, it could have been confusing. But I felt like I had a good grasp on things like, what's 32% of 8%, and what does that look like?
IN: That's great. Can you be more specific about what context in geology that came up? What were you looking at?
Carol: We were looking at these maps of the Earth's surface, and the percentages of it in mountains, or in oceans, or at what depth, and then what percentage of that is where in the world, and it's a lot of breaking down percentages.

An example of an interchange in which the student made a prompted connection between her QL course and a subsequent science course began with my reminding Erica of a Quantway task involving inverse variation. After prompting her with a specific science context, she connected both tasks through the mathematical property of inverse variation:

IN: Now what I would like for you to think of is this: Have you seen anything like this task so far in your astronomy course?
Erica: [Pauses] No, not really.
IN: Okay, have you studied the relationship between brightness, luminosity, and distance at all?

Erica: We did some with stars and the distances, yeah.
IN: So do you remember the relationship? Between how bright a star is and how far away it is?
Erica: Yeah, the further star is, you'd have to, it's not as bright. Oh yeah, for sure. The further to a star, the dimmer it is.
IN: So is there a connection to these Quantway lessons?
Erica: So, yeah, like the more miles you drive, the cheaper it gets to rent the car. They're all like an inverse.
IN: All?
Erica: I mean both situations.

In a follow-up interview with Erica, I again provided a task from Quantway involving inverse variation. This time, however, I prompted her with a different science context (Wien's law), but she struggled to report any connection:

IN: Okay, can you think of anything else in your astronomy course like this?
Erica: This kind of thing?
IN: Like this Quantway lesson?
Erica: (Pause) I don't think so. I'm pretty sure that's it.
IN: Has she [instructor] talked at all about wavelengths and temperature?
Erica: There was one like a diagram to show sun rays, or something.
IN: Okay?
Erica: I don't think I wrote that down. You had to say, oh which one would be more- there's an equation for that.
IN: Okay, do you remember this? [Drawing graph of Wien's law]
Erica: Yeah, we did that.
IN: Do you remember what's going on here?
Erica: Yeah, no. At least, not that I can remember. I mean, I remember her talking about it, but that's about it. Sorry.

Finally, there were instances in the transcripts in which a student made what I would consider to be a *mathematically incorrect* connection between a QL task and a general education science task. I wish to be very careful in using this term, however, because under Lobato and Seibert's (2002) re-conceptualized view of transfer, it is up to the student to decide the extent to which two tasks are similar or different (as opposed to the researcher stipulating the extent to which two contexts share underlying mathematical structure). Nevertheless, it would be intellectually dishonest if I considered all of the students' statements as mathematically correct.

Admittedly, there were only three times in the transcripts where students appeared to be making connections in ways that were mathematically inappropriate (it was much more likely that a student would refrain from reporting any connection at all). One example is in this interchange between Gary and myself about a task in his astronomy course. We had been discussing a task from Quantway in which students considered the differences between exponential, polynomial, and linear curves. In that task, they had to consider which type of curve was the best fit for a scatter plot.

Gary: Right, that one [the polynomial] we did squared and third degree. And tried to see which curve was the, well, the best for the data. If I recall.

IN: That's great. So if you think about your astronomy course so far, have you had to do anything like that?

Gary: This image reminds me of the wavelengths that we do. So a wave moving through space. It curves like that graph of the polynomial. The wave coming toward us or leaving us. That whole thing.

IN: Can you explain that, or maybe, can you just sketch what you're thinking about?

Gary: Sure. I mean, it just looks like [sketching a representation of a light wave] this isn't very good, but–

IN: No, that's fine.

In this exchange, Gary tried to make a connection between the pictorial representation of a light wave he had seen in his textbook, and the graph of a polynomial he had drawn in Quantway. Indeed, there are certain surface-level similarities between the two graphs, but it is certainly not the case that a light wave can be described as a behaving like a polynomial function. In this sense, I coded Gary's connection as mathematically incorrect.

Overall, finding five illustrates the extent to which these particular students made connections between tasks in their previous QL course, and specific tasks in their general science courses. The conditions that associated with spontaneous connections, prompted connections, lack of connection, or incorrect connections, are a subject of the next chapter. Furthermore, the qualitatively different ways that we see students making connections across different contexts will aid in interpreting findings one and three.

Chapter Summary

This chapter presented five major findings from this study, organized according to the study research questions. Data from individual interviews with student and professors, as well as a focus group conducted with students, revealed participants' perceptions of quantitative literacy in general education science courses. In the tradition of qualitative research, this chapter included extensive quotations from study participants. By using the participant's own words as data, I am attempting to build the reader's confidence that I have accurately represented the people and situations being studied. This chapter represented my attempt at thick description, and it is hoped that the reader has gained some sense of both the relevant data, as well as the participants' personalities.

A primary finding from this research is that the students were able to describe connections between tasks in a quantitative literacy course and tasks in their subsequent general education science courses. These connections took the form of recognizing certain mathematical/statistical components that connected both academic experiences. These components included data analysis and representation, basic numeracy, algebraic reasoning, spatial/geometric reasoning, and reasoning about chance and uncertainty. Some students made more connections in one category and some in others, but the overall picture is one in which non-STEM majors recognize aspects of quantitative literacy in their science courses. The different ways in which the students made connections across contexts seems to be mediated by several factors, including scientific context, and I will develop this idea more fully in the next chapter.

A second finding of this research was that instructors of general education science courses report that their courses require many different mathematical/statistical components of QL. In general instructors described more opportunities for students to engage in data analysis and representation than any other QL component. Other components featured in instructor reports included algebraic reasoning, basic numeracy, spatial/geometric reasoning, and reasoning about chance and uncertainty. The overall picture is one in which science instructors can identify important aspects of QL as being necessary for completing tasks in their courses. There were qualitative differences between the ways in which instructors described science tasks and the ways their own student(s) described the same tasks. Furthermore, instructor reports of the quantitative aspects of their courses were often, though not always, colored by the instructor's perceptions of the students' mathematical abilities.

The third finding from this study was that student descriptions of tasks in general education science courses contain several different levels of QL-demand. Students reported tasks in which they merely had to know the meaning of terms and phrases, tasks in which they had to distinguish between different representations, tasks in which they had to derive meaning from quantitative representations, tasks in which they had to apply mathematical techniques, and tasks that required higher order thinking. Students reported fewer opportunities to engage in higher order thinking than in other levels of QL demand.

The fourth finding from this research was that although instructor descriptions of tasks in their general science courses contain many different levels of QL-demand, instructor task-descriptions contain fewer examples of higher-order thinking than task-descriptions given by students who had previously taken a QL course. While a few instructors reported opportunities for students to engage with higher order thinking, most identified tasks in which the highest levels of QL demand required were applying mathematical techniques or deriving meaning.

The fifth finding was that the students made connections between tasks in their QL course and tasks in their science course in qualitatively different ways. In some instances, students could spontaneously identify a science task that shared underlying mathematical characteristics with a given task from their QL course. In other instances, students were able to make such connections only after the researcher provided both the QL task and the science task for them to consider. On yet other occasions, students were unable to report a connection between the two contexts even when the interviewer provided both tasks. Finally, there were occasions in which students would attempt to connect a QL task and a science task in ways that were mathematically inappropriate.

In the following chapter, I will attempt to synthesize and interpret these findings, ground them in the context of existing literature, and compare and contrast them with existing theories. I also explain how one or more findings help us interpret others, and how theories of knowledge transfer between mathematics and science courses for undergraduates can shed some light on these findings.

CHAPTER V: ANALYSIS, SYNTHESIS, AND INTERPRETATION

Introduction

> Science, in all its major branches, seeks not only to describe the phenomena in the world of our experience, but also to explain or understand them.
>
> – Carl Hempel, *Aspects of Scientific Explanation,* 1965

The purpose of this dissertation was not only to describe the experiences of community college students and instructors with quantitative literacy in general science courses, but to begin to understand and explain these experiences. In particular, I hoped to better understand the kinds of connections students and instructors make between tasks in a QL course and quantitative tasks in subsequent general science courses. I also wished to understand how students and instructors described science tasks in terms of levels of quantitative literacy demand.

By doing so, the field may gain some new insights into the quantitative literacy demands of general science courses, and the ways in which students connect quantitative ideas across courses. This in turn may push us to think more deeply about the role of QL courses in the broader picture of undergraduate mathematics education. At present, reports on the benefits of QL courses are mainly phrased in terms of pass rates and completion times, and these metrics are used to compare QL courses with other gateway mathematics courses such as College Algebra. While important, such a perspective offers only one lens on the experiences of students who have taken a QL course. To help provide a broader perspective, this study addressed the following research questions:

1. Which mathematical/statistical components of a specific QL course (Quantway) do students report in tasks from subsequent general education science courses?
2. Which mathematical/statistical components of a specific QL course (Quantway) are to be found in instructor descriptions of tasks in general education science courses?

3. What levels of QL-demand characterize student descriptions of tasks in subsequent general education science courses?
4. What levels of QL-demand characterize instructor descriptions of tasks in general education science courses?

This study relied on a form of naturalistic inquiry (Lincoln & Guba, 1985; Glaser, 2004) to collect qualitative data through in-depth, semi-structured interviews, focus group discussions, and limited summaries of science documents. Study participants included six community college students who had all passed a specific QL course called *Quantway* (Carnegie Foundation for the Advancement of Teaching, 2012), as well as five instructors who taught the general science courses in which these students were enrolled. The data were coded, analyzed, and organized by categories and sub-categories from the conceptual framework presented in chapter two.

The analytic categories used to code the data were directly aligned with these research questions. These categories then served as a backbone from which I presented the findings in the previous chapter. In analyzing data, I searched for patterns within these categories, as well as connections across categories. As an additional layer of analysis, I explored existing research and literature for relevant theories and themes, to see how my own data compares and contrasts with larger issues in the web of research.

In the previous chapter, I presented the main findings from this study in narrative form, organized by the research questions. By doing so, I hoped to give the reader a sense of the environment in which the study occurred, the personalities of the research participants, and salient examples from the vast trove of qualitative data that the study generated. Providing this rich description of the research, however, resulted in splitting apart sections of data into well-defined bins. The purpose of this chapter is to shed a holistic light on the research, and provide interpretive insights. Whereas the previous chapter presented facts, figures, and discrete packets of data, this chapter attempts to synthesize the findings into a cohesive whole. In doing so, I draw from literature on quantitative literacy, transfer, and task implementation. Many of the findings from this study are not conclusive, and some may not even be immediately helpful toward advancing our understanding of the role of QL courses in undergraduate mathematics education. From my perspective, I hope to start a conversation – not have the final word.

Analytic Category Development

Upon inspection of the findings from the previous chapter, including analysis of the concentrated data tables and descriptions provided by both students and instructors, certain themes and patterns began to emerge. In all likelihood, the reader has already formed some tentative impressions as to which aspects of the findings are particularly intriguing. I can only address the themes that stand out to myself as the researcher, and trust that others will pick up where I leave off. One of the exciting (though possibly vexing) aspects of this kind of research is that there is no definitive end to a particular research program, and every loose end can become a new avenue of inquiry.

From my perspective then, one primary finding of this study is that community college students who take a QL course both recognize mathematical/statistical components when they re-appear in subsequent science coursework, and are able to describe connections between tasks in two different academic courses. Related to this finding, student science instructor task descriptions featured the QL component *data representation and analysis* more than any other. The first analytic category I will discuss is therefore "Observations on the mathematical/statistical components of general science courses". This category speaks to Findings one and two, as well as Finding five.

Quantitative literacy is much more than a list of mathematical or statistical techniques. It includes knowledge of different ways of thinking, understanding what quantitative skills to employ, and a disposition to engage in quantitative thinking (Hughes-Hallett, 2003). Therefore, I envisioned a second dimension for analyzing student and instructor reports – levels of quantitative literacy demand (as suggested by Frith & Prince, 2009). A primary finding related to this dimension is that although student and instructor reports of tasks in general science courses indicate multiple levels of QL-demand, there are fewer reports that include *higher-order thinking* than the other levels of QL-demand. Furthermore, student descriptions of science tasks tended to include aspects of the higher levels of QL-demand more frequently than descriptions of tasks provided by science instructors. The second analytic category I will discuss is therefore "Observations of the quantitative literacy demand levels of general education science courses". This category speaks primarily to findings three and four, but also touches on finding five.

Mathematical/statistical Components in Science Task Descriptions

Findings one and two report a series of mathematical or statistical components that appeared in student and instructor reports of tasks from several general education science courses. There was general overlap between student and instructor reports in terms of specific mathematical/statistical categories. For example, both groups reported more tasks involving data representation and analysis than any other category. Descriptions featuring basic numeracy, as well as algebraic reasoning also featured prominently in reports from both groups. Instructors tended to report more tasks involving algebraic reasoning than did students. Reports featuring geometric reasoning represented about one-fourth of all science tasks. Tasks involving reasoning about chance and uncertainty appeared with least frequency, but still formed a significant portion of the data.

Why is it important that students were able to identify these mathematical/statistical components in their science courses? One might object that this study did not generate any data about how the students actually performed on the quantitative tasks they described. What is indicated by the fact that students could make connections between science tasks and previous quantitative experiences? To what extent was the students' ability to describe tasks a product of their previous QL coursework, the science context, or of researcher prompting? Let us consider these questions in a logical order.

Aspects of data analysis and representation appeared prominently across many different scientific disciplines. The sample for this dissertation included reports originating from both the physical (geology, geography, and astronomy) and biological (human anatomy and physiology, cellular biology) sciences. Does this mean that data analysis and representation is the most prevalent aspect of QL when one engages with scientific ideas? Perhaps there are other explanations for the preponderance of this category.

First, it could be that the make-up of this particular sample affected the results. For example, there were no students enrolled in courses such as physics or chemistry (courses not generally taken by non-STEM majors at this community college). Perhaps courses like physics require students to spend much more time engaged in algebraic reasoning than in interpreting graphs, but the sample for this study precludes such a discussion.

Second, it could be that students noticed (and reported) a lot of graphical interpretation tasks because data analysis was a major component of Quantway, and they were more prepared to look for this aspect of QL than for the others. If so, Finding One may be due to the students' QL course producing a priming effect (Kahneman, 2011) as opposed to any real preponderance of data analysis tasks in science courses. It is true that the Quantway curriculum places a heavy emphasis on teaching students to read, interpret, and create representations of data. Yet this alone cannot account for the frequency with which this component appeared in science task-descriptions, because science instructors (who had not taken Quantway, and therefore did not experience the priming effect) also reported data analysis tasks more frequently than other QL components. Thus, one explanation for the findings from this study is that that undergraduate science courses taken by non-STEM majors in community colleges are significantly data-driven.

Student and instructor task-descriptions featuring basic numeracy are plentiful, and the contexts are broad. Aspects of basic numeracy appeared in the neighborhood of one-third to one-half of all task-descriptions. Numeracy components often appeared in association with other quantitative components, such as interpreting displays of data, or spatial reasoning. When students spoke of the basic numeracy aspects of their science courses, they reflected mixed levels of confidence. Carol, Heather, and Erica all described the numerical computation aspects of science tasks as relatively easy. Gary and Daliah expressed certain trepidation over the kinds of calculations they had to do, especially when faced with multiple arithmetical operations in one problem (e.g. the formula for gravitational force between two bodies). The instructors in this study occasionally described their students' numeracy abilities using particularly negative language.

Instructor reports that featured algebraic reasoning primarily focused on the use of variables, how changes in one variable might effect changes in other variables, and the need to re-arrange equations to solve for a particular variable. These types of algebraic reasoning are similar to a conception of algebra as the study of relationships among quantities (Usiskin, 1999). For example, Professor Geol described the continental drift rate as a relationship between distance and time: Given a known distance between two continents, and an estimated rate of continental drift, one can work backwards to determine how much time has passed since the two continents were connected. The instructors also expressed disappointment at their students' lack of algebraic abilities. Professor Geol, Professor Astro, and Professor Physio all stated that the ability to do basic algebra was the single skill they most longed for in new students. It should be noted that when instructors made negative comments about their students' quantitative abilities, such comments were made with respect to their general population of students. They did not differentiate between the students who had taken a QL course, and those who had not. Likewise, it is probably the case that some students possessed the ability to do basic algebra, but my interview protocol did not elicit such comments from instructors.

In my discussions with students, it was often challenging to elicit descriptions of science contexts involving algebraic reasoning. A typical response is given by Gary, who told me, *"I saw no x's"*. Only after prompting the students to think about algebra in a broader sense (e.g. in terms of a language for describing patterns, or a way of describing relationships between changing quantities) did the students begin to describe science tasks involving algebraic reasoning. In fact, of the twelve individual student interviews, seven interviewees initially dismissed the idea of algebra in their science courses. One way to explain this is that the students, by and large, hold a limited conception of algebra, such as the procedures one uses to solve certain kinds of problems (Usiskin, 1999). For example, Gary's remark might indicate that he is used to algebra *looking* a certain way, such as:

$$5x + 2 = 3x - 1$$

Perhaps the relative absence of formal notation throughout their science courses led the students to report fewer opportunities to engage with algebraic reasoning in science. Astronomy was a significant exception in this study.

Students and instructors both identified units as a barrier to algebraic reasoning with respect to scientific principles. Consider Erica's description of the universal gravitation task, in which she was asked to calculate the force of gravity between two planets. In particular, Erica expressed some frustration with the mix of units, variables, and constants in this formula, exclaiming, "*What is that* k *though? Do I multiply it by* g?"

$$F = G\frac{m_1 m_2}{r^2} \quad \textit{where} \;\; \mathrm{G} = 6.67 \times 10^{-11}\, \frac{m^3}{kg\cdot s^2}$$

Such a remark suggests that differences in content specificity (Bassok & Holyoak, 1989) between the students' QL course and their science course affected students' thinking. For example, calculations in Quantway frequently contain no units, whereas in a science context the units give meaning to the results. Multiplying acceleration (m/sec^2) by time (sec) gives the unit for velocity (m/sec). In Erica's description of the universal gravitation task, we can see evidence that the units, metric prefixes, and constants all combined to produce some sort of cognitive interference with respect to both basic numeracy and algebraic reasoning.

Looking at other research on this issue, Smith and Thompson (2007) argue that students' difficulties with algebra often stem from mathematics curriculum that fails to prepare them for the use of formal, rule-governed notational systems, and also from a lack of opportunities to reason about complicated relationships. In particular; "If students are eventually to use algebraic notation and techniques to express their ideas…then their ideas and reasoning must become sufficiently sophisticated to warrant such tools" (Smith & Thompson, 2007, p. 100). This study suggests that science instructors occasionally tried to reduce the sophistication of algebraic symbolism. In Carol's description of the *Itostasy* task, she claimed that her instructor (Professor Geol) removed the symbolic variables from a formula, and replaced them with the English words "pressure", "density", and "gravity". This was an interesting instructional move, perhaps made in order to bring meaning to the scientific ideas behind the symbols. Although one might argue that by doing so the instructor was eliminating the need for students to reason using abstract symbols, the English words themselves are nonetheless a form of symbolic representation.

The question remains as to what can be done about improving students' algebraic reasoning with respect to science, and which parties (QL instructors, science instructors, others) are responsible for improving students' algebraic reasoning. Placing an increased focus within quantitative literacy instruction on helping develop students' abilities to conceptualize, reason about, and operate on quantities and relationships in algebraic problems seems like a good starting point. Furthermore, findings one and two of this study suggest the importance of attending to domain-specific conditions under which students need to recognize mathematical components, both during QL instruction, and future science courses. This leads to another specific recommendation, outlined in the final chapter.

Before moving on to consider student connection-making more broadly, I wish to point out one more unexpected result. Task descriptions featuring spatial/geometric reasoning accounted for over 25% of all descriptions given by students and instructors. Geometric/spatial reasoning tasks represent only about 6% of all tasks in Quantway. Karaali, Hernandez, and Taylor (2016) note that geometry is rarely a significant component of QL courses, and if often omitted in discussions surrounding QL for undergraduates. The results of this study, however, suggest that geometric and spatial reasoning are a significant aspect of the study of science. These results agree with prior research (Black, 2005; Chang, 1999; Downs & Liben, 1991;) on the quantitative aspects of undergraduate science courses. Taken as a whole, this research suggests that although Quantway is intended to prepare students for further academic study, the amount of geometry in general education science courses is disproportionate to the coverage of this topic in Quantway.

Having considered the implications of this study in terms of the appearance of specific mathematical/statistical QL components in general education science courses, let us now proceed to answer the question: What is indicated by the fact that students could make connections between science tasks and previous quantitative experiences?

QL Tasks, Science Tasks, and Transfer

Consider the words of David Hume (1896): "The conception always precedes the understanding; and where the one is obscure, the other is uncertain; where the one fails, the other must fail also". Applying this philosophy to the current study, one might say that a student's conception of the quantitative elements of a task precedes his or her understanding of those same elements. Therefore, it is important to note that the students in this study took this first step toward understanding by recognizing different quantitative aspects in science tasks.

Furthermore, the reader will recall the method by which students were asked to describe science tasks: The researcher provided the student with a task from his or her QL course (such as calculating costs associated with car ownership) and asked the student to think of task(s) in a science course that they believed were similar. This method initially put the responsibility on the student to think up a science task and to describe the connection with the given QL task. There were many occasions where the researcher had to provide the science task as well as the QL task (at which point the student may or may not be able to report a connection). Nevertheless, the starting point for these discussions was a non-science task. I posit that the students' ability to identify similarities between a science task and a QL task suggests that the students were transferring knowledge from one educational experience (their QL course) to another (their subsequent science course). To justify this contention, let us consider some important ideas regarding knowledge transfer.

Analogical transfer studies typically involve training a subject to complete one task, followed by testing the subject with a novel task that is analogous to the first (Barnett & Ceci, 2002). The researcher usually looks to see how much of the training transfers to the analogical task. Studies of analogical transfer have yielded many apparently conflicting results. Scholars note the common failure of transfer studies to show that training in one context or on one type of problem generalizes to related problems in different contexts (Schooler, 1989). Detterman (1993, p. 5) notes, "Transfer has been one of the most actively studied phenomena in psychology …reviewers are in almost total agreement that little transfer occurs".

In contrast, some studies suggest that human beings can and do transfer knowledge across contexts. One early study (Judd, 1908) found that certain types of training can have long-lasting mental effects and produce generalized thinking that extends past the specific training a subject received. More recently, Halpern (1998) noted that critical thinking can be learned in ways that promote transfer to novel contexts.

In this present study, I will not attempt to solve a psychological problem that has existed for over a century. Instead, I wish to note the importance of the transfer issue, and claim that the students in my study demonstrate transfer – if transfer is defined in a very particular way. In most studies of analogic transfer, the researchers decided *a priori* that two tasks (the training task and the novel task) shared significant features, but this was not the approach I used in this study. It seems plausible that the conflicting results we see in transfer studies may be due in large part to the types of tasks selected, and the rubric by which performance was measured. In other words, I suggest that the same data might be used as evidence either for or against the existence of transfer depending on definitions and researcher assumptions. In this, I agree with Lobato (1996) who argued for a new way of measuring transfer.

Actor-oriented transfer (Lobato, 1996; Lobato & Siebert, 2002) is defined as the students' personal construction of relationships between activities, or the extent to which the actors see contexts as similar or different. Under this theory, students actively invent and reorganize relationships between two contexts. Students' ability to construct such relationships is the measure of knowledge transfer (as opposed to performance of specific procedures or the application of specifically learned facts). Researchers find evidence for actor-oriented transfer by examining student discourse for reports that their perceptions or behavior have been influenced by previous activities, and investigate how students interpret two situations as similar.

Under this lens, a student who is given a QL task and is able to both come up with a related science task, and describe how the tasks are related, shows strong evidence of actor-oriented transfer. Even in a case where the researcher has to provide both tasks, evidence for transfer may be found if the student can describe how the two tasks are related. I believe that Finding One, and in particular the student quotes that support finding one, imply that actor-oriented transfer has occurred for all six students in this study.

There is a relationship between transfer and quantitative literacy more generally. Note that most definitions of QL include something similar to *a disposition to use mathematics or statistics in everyday contexts*. This implies that the quantitatively literate person is able to apply knowledge gained in one context (perhaps a classroom) in another (perhaps the grocery store). If a person cannot transfer knowledge, then it seems difficult for that person to be considered quantitatively literate under common definitions of QL. For example, in Hughes-Hallett's (2003) description of quantitative literacy transfer is implicit [emphasis added]:

> A mathematically literate person grasps a large number of mathematical concepts and can use them in mathematical contexts, but may or may not be able to apply them in a wide range of everyday contexts. A quantitatively literate person may know fewer mathematical concepts, *but can apply them widely* (p. 92).

Does finding one suggest that the six students in this study are quantitatively literate? It at least suggests that the students were able to recognize a mathematical or statistical technique from one context (their QL course) and were beginning to understand how that same component helps make sense of a task in another context (their science course). The data also support a claim that each student recognized mathematical/statistical components in multiple scientific contexts.

Furthermore, quantitative literacy is not something a person *has* or *lacks* in entirety. Just as with language literacy, quantitative literacy can be considered as a spectrum ranging from novice to mastery (Wiggins, 2003). The evidence from this study indicates that these students are all beyond the novice stage in their QL because they are able to both recognize the importance of a certain technique, and that they should apply the technique in different contexts. Nevertheless, knowing when and where to apply previously learned quantitative skills seems to require metacognitive abilities that vary greatly by student. Carol, Heather, Kelsey and Erica seemed more comfortable connecting the quantitative components of their science courses back to Quantway than Daliah and Gary.

Finding five provides additional insight to issues of transfer in this study. On certain occasions, the students spontaneously provided a science context that they deemed similar to a Quantway task, and also told the researcher why the two contexts were similar. On other occasions, the researcher had to provide both the Quantway task and the science task, and the student was able to describe similarities. On yet other occasions, a student reported no connection between tasks, or even suggested mathematically inappropriate ways in which two tasks were related. How might we account for these different responses? What factors contribute to the likelihood of a student either making connections or struggling to connect different quantitative experiences?

Conditions Affecting Student Connection-Making

In combining the results of findings one and five, I posit the following hypothesis: In tasks where the *scientific context* was relatively straightforward and plain, students were better able to connect mathematical/statistical components from Quantway to their science courses. In general, the occasions in which students failed to make a connection, or made an inappropriate connection, were usually instances in which the *scientific context* was more complex or non-intuitive. That is, science contexts can interfere with a student's ability to process a connection between two academic tasks. This is not to say that every student will find the same contexts to be straightforward, or the same contexts to be non-intuitive. In addition, in the context of an interview, less complex contexts are likely easier for students to describe and report. Furthermore, I recognize that non-intuitive contexts have a place in general education science courses – indeed, to avoid them would be to shortchange students of opportunities to learn about many powerful ideas in science.

This hypothesis is supported both by evidence from this study and by research on transfer. Let us first consider examples in which the science context is straightforward: Kelsey described a clear connection between reading and interpreting graphs in a Quantway task and similar tasks in her anatomy and physiology course. In particular, she volunteered (a spontaneous connection) the example of stimulated muscle contraction. This is an example of what I would classify as a relatively straightforward scientific context. Many of us have experienced a muscle contraction in response to a stimulus. There is a brief moment of considerable contraction, followed by a longer period of gradual relaxation. The quantitative literacy needed to make sense of the graph of this phenomenon is straightforward, and the graph of the phenomenon agrees with our intuition. It does not appear from Kelsey's description of the task that the scientific context interfered very much with her ability to make a connection back to her Quantway course.

A second example of a scientific context that seems to agree with one's preconceived notions of the natural world is the relationship between brightness and distance of stars. Gary and Erica both described the *brightness/luminosity/distance* task as being similar to a Quantway task involving inverse variation. They noted that the further a star is from an observer, the less bright it appears to be. In fact, the students' descriptions go even deeper because they explained that for two stars of equal luminosity, whichever is further away would appear less bright. Furthermore, Gary and Erica accurately described the relationship as non-linear and mentioned working with non-linear curves in Quantway. Again, this scientific context is one that seems in line with one's expectations: We know from personal experience that far away objects are more difficult to see, and that the sun appears to be the brightest object in the sky, although it is not the most luminescent.

Astronomy tasks as reported by students and instructors also provided an example of a scientific context that *did* appear to interfere with a student's ability to form connections. In conversations with Erica and Gary, I asked them about the *Wien's Law* task (the relationship between temperature, peak wavelength, and color of a star). Even though this is also an example of inverse variation, neither student described any connection between this task and the given Quantway task. Even after I provided additional prompting by sketching the graph of Wien's Law, both students recalled discussing it but neither offered much description of the task. We know from the instructor interview that the students had seen the graph and spent class time discussing what the graph represented. Under my hypothesis, the scientific context interfered with these students' ability to make a quantitative connection. Unlike the relationship between brightness and distance, the notion that a cooler star would appear 'redder' is not a concept with which Erica, Gary, or myself, has much experiential knowledge.

Even in these few examples, we continue to see just how challenging it is to determine whether or not a student is able to transfer knowledge from one context to a novel context. For example, did Erica transfer her knowledge of inverse variation or not? Toward this end, Barnett & Ceci (2002) conceptualize transfer as occurring across a spectrum as opposed to either happening or not happening. This spectrum allows researchers to discuss transfer in terms of *near* or *far* transfer, depending on many differences between the two contexts (see Figure 14).

How might this framework help us interpret the data from our present study? In terms of this taxonomy for transfer, the different contexts (Quantway task vs. Science task) represent differences in *knowledge domains*. A student in Quantway learns about inverse variation primarily through examples involving personal finances (gas mileage, spending habits, etc.). In astronomy, inverse variation is be found in many phenomena, including those mentioned above, which have nothing to do with personal finance.

	Near ←				→ Far
Knowledge domain	Mouse vs. rat	Biology vs. botany	Biology vs. economics	Science vs. history	Science vs. art
Physical context	Same room at school	Different room at school	School vs. research lab	School vs. home	School vs. the beach
Temporal context	Same session	Next day	Weeks later	Months later	Years later
Functional context	Both clearly academic	Both academic but one nonevaluative	Academic vs. filling in tax forms	Academic vs. informal questionnaire	Academic vs. at play
Social context	Both individual	Individual vs. pair	Individual vs. small group	Individual vs. large group	Individual vs. society
Modality	Both written, same format	Both written, multiple choice vs. essay	Book learning vs. oral exam	Lecture vs. wine tasting	Lecture vs. wood carving

Figure 14. Taxonomy for transfer (Barnett and Ceci, 2002, p. 621)

Looking at the left column, we note that differences between *physical contexts* also exist in this study. The students were asked to think about inverse variation in different classrooms. The *temporal context* is also important because the students experienced a gap of several months between thinking about inverse variation in Quantway and in their science courses. Both Quantway and the science courses were academic experiences and thus represent similar *functional context*s, although the interview context was not as clearly academic. It is likely that there were also differences in *social context*, and *modality* between the Quantway course and the astronomy course, and certainly between both of those experiences and the social context of an interview or focus group. However, in this study, the knowledge domain seems to be the greatest factor in determining whether students were asked to engage in near or far transfer.

Using the Barnett and Ceci (2002) taxonomy allows us to be more specific about what exactly the data from this study suggests. For one, it suggests that these students might be more successful in making connections between QL tasks and science tasks when differences in knowledge domains between the tasks were not too great. When the knowledge domain for a science task represented *far transfer*, students reported fewer (or occasionally mathematically incorrect) connections.

At first glance, it may appear that Lobato and Siebert (2002) disagree with Barnett and Ceci (2002) with respect to who is responsible for determining whether two contexts are similar or different. In the former case, it is the actors who have the authority for determining the nearness or farness of two contexts. In the latter, it is the role of the researcher to determine where along a spectrum two contexts fall in terms of similarity. I see these two frameworks as complementary in that the taxonomy of Barnett and Ceci helps us understand *why* an actor might see two contexts as similar or different.

An alternative (and perhaps complementary) explanation for findings one and five is that student thinking is not characterized by the mere presence or absence of understanding, but is better described as falling somewhere on a continuum between deep and surface-level understanding. I can, for example, grasp the general concept of a phenomenon such as the *Doppler effect* without a deep understanding of the physical processes behind sound or light waves, pressure, frequency, and so on. Thus there is a distinction between understanding a principle at a deep level (and thus the ability to connect principles across contexts), and understanding at a more surface level (which may inhibit me from making connections). Perhaps Judd's (1908) participants learned a principle at a deep level, which is why they were able to transfer that principle to a novel task, whereas participants in other transfer studies (e.g.

Detterman, 1993) failed to demonstrate transfer because they did not understand the principle at a deep level.

The notion of deep versus surface learning is attractive, but it can only account for part of the picture. What would we say about the presence or absence of deep learning if a student could describe a mathematical principle in some follow-up tasks but not others? For example, did Gary possess deep or only surface level understanding of inverse variation? Since he was able to recognize that mathematical component in one task (brightness/distance) but not another (Wien's law) we cannot say for certain. Perhaps one explanation is that both the deep/surface distinction and my scientific-context hypothesis combined to produce the variety of results we see in this study.

Another interpretation comes from the theory of situated cognition, which states that our conceptions of mathematical notions are tied to the particular problems in which those conceptions emerged. For example, Newton's conception of function was substantially different than Dirichlet's because each man was working with a different phenomenon. Researchers have long suggested that cognition is strongly situated in context, and that context affects our ability to perform mathematical operations (see Greeno, 1991, 1997; Leinhardt, Zaslavsky, & Stein 1990; Putnam & Borko, 2000). For example, unschooled street vendors were 98% accurate in calculations involving the cost of coconuts during actual business transactions on the streets, but their accuracy dropped to 37% on written tests of identical mathematical problems (T. N. Carraher, Carraher, & Schliemann, 1985).

By and large, subjects fail to solve transfer tasks unless prodded to use previously learned solution methods. (D. Carraher & Schliemann, 2002, p. 4). One difference between those kinds of studies and my present work is that in this study I was not assessing students' ability to *solve* *problems*, but rather to report whether or not two tasks are similar. Under Greeno's (1997) version of situated cognition (see Nunez, Edwards, & Matos, 1999 for yet another), we might interpret Gary's occasional ability to recognize inverse variation based on the extent to which each context was similar to the context in which he learned inverse variation (either in Quantway, or earlier in his other mathematical studies).

Coming full circle, let us return to Hume (1896) [emphasis added]:

> When any object is presented to us, it immediately conveys to the mind a lively idea of that object, which is usually found to attend it; and this determination of the mind forms the necessary connection of these objects. But *when we change the point of view*…the uniting principle among our internal perceptions is as unintelligible as that among external objects, and is not known to us any other way that by experience (p. 169).

In terms of my findings, it is quite possible that the students already possessed a "lively mental idea" about certain mathematical components (such as inverse variation), which they usually conjured up whenever the idea was mentioned in Quantway. But when asked to change their point of view, (e.g. to an astronomy context), their internal perception of inverse variation was challenged, and became less intelligible. More experience with mathematical ideas in an astronomy context would help build up their perception again. I return to this theme in the final chapter.

Summary

Looking across Findings One, Two and Five, there is evidence to suggest that students are able to make mathematical connections between tasks in their general science classes and tasks in their previous QL course. The conditions under which they make such connections appear to be mediated by a number of factors, including specific science contexts, the QL context in which the mathematical notion first arose, the quality of the students' mental ideas about the specific mathematical principle, and even mathematical notation.

In addition, the findings of this study suggest that general education science courses for non-STEM majors feature a significant dose of data analysis and representation. Basic numeracy, as well as algebraic reasoning also appears prominently in both student and instructor reports of science tasks. This finding agrees, in part, with past policy reports on the quantitative aspects of collegiate science courses (Ganter and Haver, 2011) as well as with prior research. For example, Mayes, Peterson, and Bonilla (2013) noted four elements of QL related to science: numeracy, measurement, proportional reasoning, and descriptive statistics/basic probability. In this study, over 25% of all descriptions of science tasks featured some aspect of geometric or spatial reasoning.

The relatively high number of data representation tasks connects with findings three and four, because those same tasks often involved the QL-demand level *deriving meaning*. In order to synthesize these findings further, I now turn to a different analytic lens: Levels of quantitative literacy demands.

QL-demand Levels in Science Task Descriptions

Resnick (1987) wrote, “The goals of increasing thinking and reasoning ability are old ones for educators, . . . such abilities have been the goal of some schools at least since the time of Plato” (p. 7). Whereas analytic category one dealt with the placement of specific mathematical/statistical components in science courses, and the conditions under which a student might recognize those components across contexts, this category deals in the realm of reasoning. In particular, I explore the kinds of quantitative thinking required by general education science courses, as perceived by both students and instructors. In particular, I present a synthesis of findings three and four.

Findings three and four had to do with the levels of quantitative literacy demand (Frith & Prince, 2009) required by tasks in specific general science education courses for non-STEM majors at a community college. The process for determining which tasks were associated with which levels of QL-demand was two-fold: First, I relied on experiential descriptions from both students and science instructors. I then coded these descriptions based on five different levels of QL-demand. Admittedly, this was a clear case of the researcher imposing a framework on the data, but others who coded the same tasks tended to assign the same codes over 85% of the time.

A second method employed to determine the QL-demand levels of science tasks was the use of a focus group with a subset (4 of 6) of student participants, in which a significant portion of the conversation involved students discussing levels of QL-demand associated with various science tasks. Conversation on QL-demand levels also occurred during individual student interviews (particularly in the second round). By using this approach, I wanted to see the extent to which the students might perceive that different science tasks required different kinds of quantitative thinking. This conversation went well beyond a discussion of which tasks were *easy* or *difficult*, and I pressed the students to think about *why* certain tasks were more or less challenging than others.

Thinking about such issues is significant because a body of research indicates that students (and even instructors) often struggle to distinguish between notions such as *conceptual* difficulty and *procedural* difficulty (see Hiebert & Lefevre, 1986 for a landmark summary of such research). Furthermore, a half-century's worth of studies of student motivation (Battle, 1965; Chouinard, Karsenti, & Roy, 2007; Locke & Latham, 2002) suggest that understanding *why* a task is difficult is one of many factors that contributes to student persistence in task completion. When students can see a challenge as tangible, especially if when doing so they can recognize the challenge as one similar to others they have already overcome (e.g. similar in terms of procedural difficulty), their *expectancy* (Battle, 1965) increases with respect to completing the task. In addition, one aspect of QL (Steen, 2004) is a disposition to appreciate the role different reasoning abilities.

On the other side of the desk, instructors who understand which aspects of a particular task are challenging for specific reasons, are better able to assist learners in overcoming such challenges, as opposed to simply lowering the cognitive level of a task to make it easier for students (see Henningsen & Stein, 1997 for a deeper explanation of this phenomenon). Such were the theoretical ideas that came to the forefront during my analysis of study findings.

QL-demand Levels in Student Task Descriptions

As early as 1912, Thorndike noted the role of the instructor in focusing student attention on particular aspects of classroom activity, whether for mastering specific content, or for helping students think deeply and thus self-educate (p. 197). A century of research has confirmed the role of the teacher in influencing what students attend to in the classroom. Therefore, it is only with significant reserve that we can discuss the student descriptions of QL in science tasks as something independent from the instructor descriptions. Taken together, findings three and four provide at least two interesting avenues worth pursuing: First, student task-descriptions of tasks included several different levels of QL-demand, but relatively few descriptions of higher-order thinking. Second, student task-descriptions were characterized by containing generally higher levels of QL-demand than instructor task-descriptions. Let us consider each of these avenues in some depth.

Not only did student accounts feature five levels of QL-demand, all six of the students were able to point to specific tasks in their science courses that they felt featured different kinds of QL-demand. For example, in the focus group, I asked the students to think of two tasks, one that did not require higher-order thinking and one that did. Students were generally able to differentiate between such tasks. For example, Carol described the requirements of the *river entering a gorge* task as not requiring higher order thinking, whereas she described the *isolines* task as requiring reflection (a marker of higher order thinking). Likewise, Heather described the *global warming predications* task as requiring higher-order thinking because the task made her think about why there are different predications for rising temperatures, and how uncertainty plays into scientific predications. During the focus group, when I asked students to come up with a task that did not involve higher order thinking, Heather told the group about a task involving the angle of the sun's rays at different latitudes on Earth:

Heather: "So the closer you are to…the North Pole, the more air, I think, the rays pass through. So it's like, a different angle. Like if the rays hit you straight on, it's going to be more concentrated, and that area is going to be heated better.

IN: And which of these [QL-demand] levels do you think this task required?

Heather: Yeah, well, I'd say these first three. There really isn't any calculation, right? And I mean there's not even a lot to think through. It's just something where you look at this picture [Figure 15] and figure out what's going on. But we didn't really do anything more than just learn the rule.

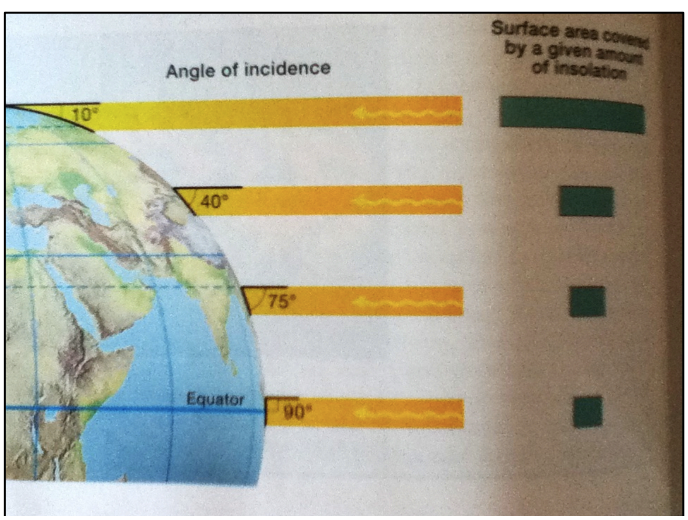


Figure 15. Variations in heating due to latitude (Hess & Tasa, 2013, p. 80)

Heather's words are encouraging, because one of the goals of QL instruction is to help students understand that there are different types of quantitative thinking that one can bring to bear in solving a problem (Gal, 1993, 1997). The reason this kind of metacognition is important lies in the idea that student perceptions of tasks strongly influence their motivation in persisting toward solutions.

Reports of science tasks in this study differed in the types of end-products the tasks required: Some tasks called for generative responses, i.e., computing a number or generating an estimate. Some required multi-step operations, and using the results to make decisions. Other tasks called for interpretive responses, i.e., making sense of quantitative statements or data displays or being able to ask critical questions about the information and arguments presented without performing any calculations. These types of tasks, and many mixed types, varied in terms of the quantitative literacy demands they require.

It appears from the findings of this study, that the students were able to identify various quantitative literacy demand levels in science tasks, and understand why certain tasks were more cognitively challenging than others. While the instructors might have associated quantitative demand levels with problems in more abstract ways (discussed below), the Quantway students in this study were able to recognize a fairly broad range of QL-demand levels within different science tasks.

The second avenue of inquiry I would like to address is the finding that student task-descriptions featured more instances of higher-order thinking than instructor task-descriptions. One might be tempted to interpret these findings as evidence that students simply perceived science tasks as *more difficult* than did their instructors, but reality is likely more nuanced. One possible explanation for this finding is that, because the students are not experts in the field, they do attend to different features of tasks than their instructors (Stein, Engle, Smith, & Hughes, 2008). Therefore, if a task purports to elicit higher-order thinking, through the use of key words or phrases, the students may interpret that task as actually requiring higher-order thought, regardless of how the task actually played out during the course. In this study, some tasks stood out as less structured, more complex, and longer than typical tasks (for example, the *isolines* task, and the *star mapping task* discussed below). According to Doyle (1988) students may perceive tasks as cognitively challenging when it is not readily apparent what they should do to complete the task. If so, perhaps the students in my study described certain tasks as higher-order thinking tasks, but did not consider the very real possibility that their instructor lowered the demands of the task during classroom implementation.

Evidence for this idea comes from descriptions of the *star map* task in Astronomy. A portion of Professor Astro's description of this task was included in Chapter Four, but I repeat it here along with its surrounding context:

IN: So what do you want them to do in that activity?

PA: What I *want* them to do? I'd like them to be able to think about how the night sky would appear from different points on the Earth, and why we need a consistent system for describing the location of celestial objects.

IN: And how do you– do you do that?

PA: I mean, and I admit this is an area where I usually fail, but we never get to that kind of thing. Because they don't understand the math, to be honest. We just get bogged down in just trying to find a star given right ascension and declination. I make them locate stars on the star maps that are in there. So the measurement is in degrees, but they need to know how to get increments of degrees. We talk about increments of 360, you know a degree is about this, so if we shift that way, minutes, arc-seconds. They need to be able to make those calculations.

This description certainly suggests that students were engaged with QL-demand levels such as *deriving meaning* and *applying mathematical techniques*. The description stops short of providing evidence that this task required higher-order thinking, although the instructor initially described the task goals with language ("*why* we need a consistent system for describing the location of celestial objects") that approaches higher-order thinking. In Professor Astro's description, the goal of the task seems to drift away from a focus on meaning and understanding to a focus on procedural accuracy.

Two of the student participants (Gary and Erica) also described this task. Here is Gary's description:

Gary: Yeah, that one was super hard. For me, at least.

IN: What do you think was hard about it?

Gary: Just the, the math you know? I mean, wow, all those measurements, and like, thinking about how the Earth is tilted, and rotating. I'm still not sure I know what is going on. Like, she gave us these maps and by the end I could kind of get it, get how to do the calculations. But, woah.

And here is Erica's:

Erica: The thing about that [star chart task] that I thought was interesting was that the stars appear in different places depending on where you're at on the Earth. Like, we had to say what we thought would be different about the sky if we lived in South Africa, or something. So like, and I don't remember this exactly, but there's a constellation that would appear right overhead if you are on the Equator, but it's like on the horizon if you're at the North Pole. Something like that. So the sky looks totally different up there. It was kind of cool, actually.

IN: So what kind of math did you have to do in that activity?

Erica: It was just like converting units, I guess. I mean, it was pretty confusing. Let's be honest. But I just kept thinking about how if you were trying to navigate, it would have been super hard without this system, because everywhere you'd go, the stars would look like they had totally changed positions. So I get why we need this method. I just wish it weren't so complicated.

Gary's description seems focused on the mathematical computations, in much the same way as did Professor Astro's description. Even though Gary described this task as "super hard", he did not indicate that the task required reflection, conjecturing, evaluating, or other indicators of higher-order thinking. For Gary, the task was procedurally difficult. Erica also described the mathematics as complicated, but went one step further, saying that the task gave her the opportunity to reflect on the need for a mathematically consistent system, and conjecture as to how the night sky would look from different geographical locations. Because the data for my study does not include classroom observations, I cannot comment on how the task was actually implemented in the Astronomy class. Nevertheless, at least one of the students who experienced this task described it with words that suggest higher-order quantitative thinking.

Of course, many factors inside and outside the classroom influence how students engage with a science task, including their attentiveness during instruction, their interpretations of the teacher's presentations and of the tasks they are assigned, and their entry knowledge and skills (Wittrock, 1986). One factor that mediated how students engaged with science tasks appears to be the extent to which instructors focused attention on different aspects of quantitative reasoning when assigning and implementing tasks. This leads us to consider the instructor side of the equation.

QL-demand Levels in Instructor Task Descriptions

One of the first things to strike me as remarkable about Finding Four was the low percent of instructor task-descriptions that involved higher-order thinking. To help understand this finding, I searched through transcripts of instructor interviews for evidence that the instructors *themselves* perceived few opportunities for students to engage in higher-order thinking. The results were striking: Four of the five instructors, upon seeing the Frith and Prince (2009) framework, suggested that practically *all* the tasks in their course required only the first two levels (Knowing; Identifying and Distinguishing). Professor Astro's statement is typical of such remarks: "*I wish I could do more of that* [higher order thinking]. *But honestly, most of what we* *do is in these two levels* [Knowing; Identifying and Distinguishing]. *I'd say 90%... honestly, most of them can't even do that. It's really hard for them".* As we have seen, however, Erica did engage in higher-order thinking with respect to astronomy.

Such perceptions are interesting for at least three reasons: First, because my own detailed analysis of instructor task-descriptions suggests that most science tasks actually require levels of QL-demand beyond the first two. Second, because the *reason* instructors gave for spending so much time on tasks that only require low-level QL-demand is that many students struggle with even the lower levels of QL-demand. Professor Astro is not alone in ascribing poor quantitative reasoning skills to her students. During my interview with Professor Physio, when the conversation turned toward levels QL-demand levels, he commented, *"I don't think they really know how to think*". We do not know, however, if Professor Astro's statement refers to *all* of her students, or only a subset. Third, the students who participated in this study do show some potential for reflection, conjecture, and evaluation – hallmarks of higher-order thinking.

Looking across the quotes provided to support findings two and four, one finds ample evidence of instructors commenting on where their students' thinking and reasoning abilities seem to be on science tasks, even multiple times in the same interview:

> "They have no idea. They got none of it at all. This is really depressing. I don't have a single student this semester, perhaps in the past, who was able to interpret this." (Professor Astro)
>
> "And they'd all look at me like, "What?" But it's just a proportion, right? But they don't really understand the symbols so they struggle to get the big idea here." (Professor Geol)
>
> "They don't know how to think logically." (Professor Geog)
>
> "Can they read this? No. Do they get the point of cumulative percentage? No. Okay, now elevation. Highest percentage of Earth's surface, highest percentage not cumulative, percentage. What they are doing, I don't know if they are not reading the questions, or they aren't comprehending." (Professor Geog)

> "… people were giving me these absurdly low numbers, but they don't think anything about it!" (Professor Cell)

What can we make of such statements? First, the above quotes corroborate the findings of previous research on community college instructor perceptions. For example, Mesa (2012) found that community college instructors tend to hold significantly more negative views about student competence than the students do about themselves. In general, she has found that community college students expect and believe that they can handle challenging work, that they exhibit positive mathematical behaviors, and that they are interested in improving their quantitative competencies. She found that many community college instructors believed that their students were incapable of completing challenging quantitative material.

Instructors who possess negative opinions of their students' quantitative abilities are more likely to avoid assigning challenging tasks and, if such tasks are assigned, they tend to make pedagogical decisions which result in watering-down the cognitive demands of these tasks (Henningsen & Stein, 1997). In light of this, I conjecture that the instructors in this study shied away from implementing science tasks that required high levels of QL-demand in part because they felt their students simply could not handle the challenge.

The instructors' comments in this dissertation were referring to a general population of students, and were not intended as a critique of any particular student's ability. The instructors did not make, nor did I ask them to make, a distinction between the reasoning abilities of students who had taken a QL course and those who had not. Furthermore, the fact that an instructor speaks negatively about his or her students' quantitative abilities could result from an instructor making an evaluation of where most students are in terms of reasoning abilities for the purposes of knowing how best to meet the students' needs. Finally, it should not be surprising that instructors spoke negatively about their students' quantitative abilities, because of the nature of my interview questions. I did not ask the instructors to comment on instances in which students reasoned well, but instead probed into an area that was likely a contentious subject to begin with—the mathematical preparation of incoming science students.

One might of course argue that it was the researcher who coded the task-descriptions as containing fewer elements of *higher-order thinking* than levels such as *knowing* or *identifying and distinguishing*. Furthermore, the argument might go, we only have evidence about instructor *descriptions* of tasks, and no evidence about how the tasks were actually enacted in science classrooms. Perhaps if researchers were to actually observe the implementation of tasks, with all of the attendant social norms, we would see more evidence of higher-order thinking. To all of this, I agree. More research in this area would be highly useful. Nevertheless, we can take something important away from the evidence of instructor descriptions, because the instructors' task-descriptions indicate the presence of a *social fact* (Durkheim, 1938).

The notion of the social fact stems from the idea that there is always an element of coercion in social phenomena. The source of coercion can take many forms, including colleagues, past instructional experiences, and media. In this study, the tendency among instructors to believe that students are incapable of higher levels of quantitative reasoning likely derives from both colleagues and previous classroom experiences. Professor Geog described a conversation with her colleague in the chemistry department that re-enforced a negative perception about student abilities:

> My departmental coordinator teaches chemistry. And we sit down for hours chit-chatting and comparing. She can't get them to do problems, either. And she's first semester chemistry. And also third and fourth semester. Their math skills coming in to community college, college, or University, is so far behind. (Professor Geog)

Speaking from my own experience as a community college mathematics instructor, such conversations are commonplace. Just within the context of this study, two other professors made offhand remarks that conversation among colleagues about he poor quantitative abilities of students are commonplace. Such conversations can lead to a group-mind (*l'ame collective*) in which a group of instructors come to perceive student abilities in roughly the same ways.

Other researchers have found evidence for the *l'ame collective* among instructors. Trefil and Hazen (2010) reported on a tendency of science instructors (and presumably the same is true of instructors in many fields) to fall into the fallacy of expecting that all students should 'think like us', and lament when their students fall short of this ideal. In addition, there is an expectation, as Shamos (1995) has suggested, that in order for a person to be truly scientifically literate, he or she must be able to draw independent conclusions using the same kind of reasoning that a professional scientist might apply. Trefil and Hazan (2010) note that many science instructors even view mastery of certain mathematical techniques as a pre-requisite for scientific thinking. Students who can't understand difficult mathematics, let alone basic mathematics, are thus deemed incapable of engaging with serious scientific ideas. As Professor Geol noted, *"This is college. We shouldn't be doing fourth-grade math. Once in a while, you get a student who had calculus [in high school], but even then, they've probably forgotten the basics. I mean, I taught myself the math I needed in college. But they can't do it."* In the language of Durkheim (1938), then, the instructors in this study use few higher-order thinking tasks because their own thinking is coerced by colleagues and past experiences into believing that many students can't engage in higher-order thought during science tasks

This explanation for findings three and four is somewhat limited, because it does not fully account for the discrepancy between appearances of higher-order thinking in 16.5% of student task-descriptions and in only 5.6% of instructor reports. More likely, these results can be explained by a combination of students attending to different features of a task than instructors, and the workings of the *l'ame collective* in instructor task implementation.

Summary

The findings of this study suggest that despite a broad disciplinary overlap between science and mathematics, science instructors generally avoided placing too great an emphasis on the quantitative aspects of science in general education science courses. This reluctance is due in part to instructors' perceptions of innumeracy among community college students. This perceived innumeracy is seen by science instructors as both frustrating and inescapable: Multiple instructors noted that the students' previous education (K-12 or postsecondary) failed to foster the skills necessary to make sense of the quantitative aspects of science, and that it is highly unlikely the students' skills will improve by taking a single semester general science course. The data from this study is insufficient to say exactly how this perception influenced classroom decisions. Furthermore, this study did produce evidence to show that some students do engage in higher-order thinking during a general education science course.

Overall Summary and Limitations

This chapter portrayed the experiences of a sample of students who completed a quantitative literacy course and who were subsequently enrolled in general education science courses. It portrayed science task-descriptions given by both community college students science instructors. The prior discussion illustrates the complex and multi-faceted intersection of quantitative literacy and science, as experienced by both students and instructors. The discussion revealed various QL components that students and instructors noticed throughout different science courses, and suggested underlying reasons for why certain components are more commonly reported than others. In addition, this synthesis pointed to ways in which students make connections between tasks in a QL course, and tasks in a science course. Finally, the discussion highlighted different kinds of quantitative thinking (in the form of QL-demand levels) required by tasks in a variety of science courses. I offered explanations as to why community college instructors report or indicate the presence of low levels of quantitative literacy demand in science tasks, and suggested ways to account for differences in perceptions between students and instructors.

In this chapter, I attempted to produce a holistic and integrated synthesis of the study findings. Some major challenges with the synthetic process involved distilling a large volume of qualitative information, identifying significant connections between findings, and remain faithful to report findings using a framework that makes sense for the purposes of the study. Not all of the collected data figured substantially in the findings. For example, extensive within- and across-case analysis did not reveal any particular relationships between any of the participants' demographic characteristics (age, gender, field of study, etc.) in explaining the findings.

"Human behavior is influenced by a dazzlingly complex set of incentives, social norms, framing references, and the lessons gleaned from past experiences. In a word: Context" (Levitt & Dubner, 2009). To some extent the findings in this dissertation are related only to those community college students and instructors who took part in the research. Perhaps the students were scientific do-gooders, motivated by a desire to help a doctoral researcher or advance the cause of quantitative literacy instruction. These students were relatively organized and dedicated– at least organized enough to keep regular appointments with a researcher. It is left to the reader to decide whether or not other students fit this description, and the extent to which these findings are transferrable to other settings. It is likely that at least some of students enrolled in QL courses across the country are able to make connections between the things they study in those courses and subsequent academic experiences.

One might suggest that the participants in this study were motivated to tell the researcher things that the researcher wanted to hear, because of their positive experiences with Quantway. While this no doubt played a part, the students' experience Quantway (which they often described as standing in contrast to negative experiences in other mathematics courses) led the students to tell the researcher great things about the Quantway program, not about their experiences in general education science courses. In fact, it was occasionally difficult for me to get them to talk about their science courses at all, especially in the first round of interviews. This may have been because the participants were initially invited to the study by their QL instructor, and might have thought that they were joining a study focusing primarily on Quantway. The result was that, although they may have tried to please the researcher by making enthusiastic statements about their QL course, we have less reason to think that this motive influenced descriptions of science tasks.

In looking at the data, one should ask if the very act of conducting this study might have had unexpected consequences. Perhaps one unexpected consequence is that, because the instructor interviews occurred early in the semester, instructors emphasized the QL components they had discussed with the researcher while teaching their courses. This is not unlike the educator who attends a workshop on a specific topic, and when that topic comes up in the natural flow of curriculum, they teach that topic with more detail or with greater care. Such action might have subsequently influenced the QL components noticed and described by the students.

In fact, it is very likely that participating in the study led at least one of the students to notice more aspects of QL in her science course than she would have had she not been a participant. This student was Kelsey, and the evidence is in the fact that she collected graphs (unbeknownst to me) during the last few weeks of her science course, brought them to the interview, and preempted the interview by showing me everything she had brought. Had she not been participating in the study, it is unlikely she would have gone to such lengths to think about how those handouts connected back to pervious experiences in Quantway.

For most human beings, scrutiny has a powerful effect that can lead to significant changes in behavior. One might argue that by prompting the students to think about specific science tasks during an interview, the researcher caused the task-reports to feature more QL components than might naturally occur in the normal flow of conversation. While possibly true, the point of this study was not to determine which aspects of a QL course a student would notice in a subsequent science course if left to their own devices.

Other limitations of this study were a result of methodological decisions made by the researcher. For example, I made the decision not to have a distinct category for *mathematical modeling* in my analytic framework. I discussed the reasons for this decision in an earlier chapter, but it is important to be explicit about how such a decision might have affected the findings of this study. For one, I am unable to make any claims with respect to the ways that students or instructors perceive aspects of modeling in science tasks. Throughout the interviews, both students and instructors described science tasks that required students to engage in some mathematical modeling similar to how modeling appears in the written curriculum for Quantway. Perhaps, if I were to have pursued a form of analysis that included mathematical modeling as a separate category, it would have revealed some interesting patterns between modeling tasks and tasks involving other mathematical/statistical components.

As explained earlier, my conceptual framework separates data analysis/representation from reasoning about chance and uncertainty. It could be argued, however, that understanding the role of uncertainty is extremely important if one is to analyze and represent data. Understanding how students and instructors perceive the role of uncertainty in science tasks involving data analysis/representation seems valuable—but would require a different study.

Supposing that a major goal of college education is to refine students' critical thinking abilities, the results of this study paint an optimistic picture with respect to student connection-making across quantitative courses. The results of this study indicate that the students were capable of making connections between QL and science tasks, especially with some prompting. This is good news for science instructors hoping to connect the quantitative aspects of their courses with students' previous mathematics coursework. For effective promptings to occur, however, the science instructors would need a better understanding of exactly what topics students had covered in their pervious coursework. To this optimism we must maintain a sense of caution. Instructor remarks about their students' quantitative reasoning abilities were frequently negative, and multiple instructors reported that they implement few quantitative tasks that require higher order thinking.

As noted earlier, there are alternative ways to explain the negative instructor comments that appeared throughout this study. For example, one job of an instructor is to move the students from lower levels to higher levels of reasoning. Perhaps the instructors' comments indicate recognition that many students have not yet attained those higher levels. Some of the instructors reported methods that they employ to help students make sense of the quantitative aspects of science, such as helping them interpret symbols, drawing on outside resources, and teaching students to critically read science articles. Perhaps the student task-reports featured more evidence of higher-order thinking than instructor task-reports because the two groups are viewing the tasks from different perspectives. Whereas the QL students see how far they've come in their quantitative reasoning skills, the science instructors see how far they still have to go.

The data from this study indicates that some of the students engaged in higher levels of quantitative reasoning than their science instructors expected on specific tasks. Erica, for example, engaged in higher-order thinking in the star chart task—a task that Professor Astro described as featuring only lower levels of QL-demand. In this study, however, I did not ask the instructors to comment on the quantitative skills of specific students. That is, the negative instructor comments are directed toward a general population of their students. Given that some of the students in that population are engaging in high levels of quantitative reasoning, the results of this study should give science instructors something to strive for when implementing quantitative tasks. Such thoughts lead us to the final chapter of this dissertation, in which I present certain recommendations for both practice, and future research.

CHAPTER VI: CONCLUSIONS AND RECOMMENDATIONS

School instruction is plagued by a push for quick answers.
– John Dewey (quoted in Hiebert et al., 1996, p. 15)

The purpose of this study was to explore with a group of community college students, and their science instructors, the quantitative literacy demands of general education science courses, and the ways in which students connect quantitative ideas across courses. In particular, the study sought to understand the kinds of connections students themselves make between a QL course, and their subsequent general science coursework. The conclusions from this study follow the research questions, and address three areas: (a) student and instructor perceptions of specific mathematical/statistical components of QL in general education science courses, (b) student and instructor perceptions of the levels of QL-demand required by tasks in general education science courses, and (c) the ways in which students make connections between QL and science courses. I begin by reviewing the major findings of the study organized around the three areas listed above, and draw conclusions from these findings. I then present recommendations for research and practice based on these conclusions. The chapter ends with the researcher's final reflections on the entire study.

Conclusions

QL Components in General Education Science Courses

One major finding of this dissertation is that community college students, who have taken a QL course, are able to notice many mathematical/statistical components from that course when they appear in subsequent general education science courses. Data representation and analysis was the component of students' previous QL course that they reported most frequently in tasks from subsequent science classes. Science tasks involving geometric or spatial reasoning made up over 25% of all reports. Student task-reports also contained occurrences of basic numeracy, and less frequently, algebraic reasoning. Probabilistic reasoning was reported in fewer tasks than the other components. Instructor reports of science tasks featured these components in generally the same order, although instructor task reports included more instances of algebraic reasoning than student task-reports.

A conclusion drawn from this finding is that students who enroll in general education science courses should expect to engage with a significant amount of data analysis, including many opportunities for both creating and interpreting graphical representations of data. Related to this, we can conclude that the types of data analysis required in general science courses are similar to those that the students experienced in their QL course. The warrant for this conclusion is the many occasions throughout the study in which a student was given a QL task involving data analysis, and was able to come up with a science task that shared similar features. A second conclusion drawn from this finding is that general education science courses, at least in this community college, feature a non-trivial amount of geometric reasoning. Related to this, we can conclude that if QL courses are to prepare students for the further study of science, they should prepare students to engage in geometric and spatial reasoning.

Instructors described several science tasks that required algebraic reasoning, but they also expressed a desire to include more algebra in their courses. Underlying many of the algebraic and data analysis components of general education science tasks is the notion of covariation. Understanding covariation seems to be a significant aspect of understanding scientific phenomena. A commonly reported perception was that the majority of students are underprepared to use algebra in the study of science. Drawing a conclusion from this aspect of the finding is not straightforward. It could be that these science instructors are mistaken in their assessment of the students' algebraic reasoning abilities. Alternatively, it could be that the kind of algebraic reasoning involved in the study of science differs significantly from that which students generally experience in developmental or first-year mathematics courses. Third, it could be the case that the students do possess the algebraic reasoning abilities required for the study of science, but lack the metacognitive skills necessary to operationalize this knowledge in a science context.

Levels of QL-demand in General Education Science Courses

This study revealed that tasks in general education science courses require many different levels of quantitative literacy demand, and that the majority of science tasks required *knowing*, *identifying and distinguishing*, and *deriving meaning*. Students reported fewer instances in which they engaged in higher-order quantitative thinking than in the lower-levels of QL demand. Student task-descriptions included more aspects higher-order thinking than task-descriptions provided by science instructors. All five of the instructors in this study told me plainly that they largely avoided implementing higher-order thinking tasks, but evidence from this study suggests they actually do implement such tasks. Evidence from instructor interviews suggests that this avoidance is due, in part, to a perception that the students are incapable of the kind of higher-order quantitative reasoning required by different scientific disciplines.

One conclusion that can be drawn from this finding is that making sense of scientific ideas, at least the kind of ideas generally covered in community college science courses for non-STEM majors, requires more than the ability to apply certain mathematical or statistical techniques. The ability to comprehend important scientific ideas requires that students identify connections and distinctions between different quantitative ideas, and derive meaning from graphical, diagrammatic, and textual representations of information. The students who participated in this study showed clear evidence that they engaged in these kinds of thinking.

A second conclusion that may be taken from this finding is that these community college students, who had taken Quantway, are able to perceive that science tasks require different kinds of quantitative thinking. We also see evidence that students can differentiate science tasks based on the kind of quantitative reasoning they require.

Connecting Concepts from a QL Course to Science Courses

Another major finding of this study is that these students who have taken Quantway are able to take tasks from that course, and identify tasks in a general education science course that share underlying mathematical/statistical properties. On occasion, students were able to spontaneously describe a science task that they felt shared similar mathematical properties to a QL task. More frequently, students were able to describe a mathematical connection once they were provided with both tasks. On other occasions, the students failed to report any connection between a given QL task and a given science task. Factors that seem to influence the students' ability to describe connections include differences in knowledge domains between tasks, the context in which a mathematical component first arose in Quantway, and the extent to which the science context was intuitively sensible.

A conclusion that can be taken from this finding is that community college students, even those who have only taken one or two QL courses, possess the ability to see quantitative connections between science and math tasks, but may require explicit prompting to do so. The instances in which a student failed to perceive any connection, or suggested inappropriate connections, represented only about one-quarter of all attempts, and this was in the context of an interview, not during classroom instruction. Using Lobato's (2002) conception of actor-oriented transfer, we can conclude that the students in this study did transfer knowledge from their QL course to their subsequent science courses. It appears that the Quantway program, to some extent, does prepare students for further academic study.

Following the finding that some science contexts pose greater challenges to students' ability to make mathematical connections across tasks, I conclude that many of scientific ideas presented in a general education courses are sufficiently challenging to induce cognitive conflict in the mind of an undergraduate. Thus, although the instructors did not include many features of higher-order quantitative thinking in their descriptions of science tasks, their descriptions do appear to require the synthesis and analysis of complex scientific notions that do not always agree with one's intuition.

Recommendations

In what follows, I offer recommendations based on the findings, analysis, and conclusions of this study. The recommendations are primarily for those involved with (a) designing and implementing QL courses, (b) improving general education science courses, and (c) further research.

Recommendations for QL Course Design and Implementation

The goals of the Quantway program, which also appear (in one form or another) in many arguments for teaching quantitative literacy more broadly are that students will learn mathematical skills that are useful in a variety of life experiences, including private life, in the workplace, and for further study (Carnegie Foundation for the Advancement of Teaching, 2012). This dissertation explored students' experiences with QL in their subsequent science courses. If we are serious about using QL courses to prepare students for further *academic* study, in addition to teaching QL for everyday life outside the classroom, then the conclusions of this dissertation suggest the following recommendations:

1. Carefully select the contexts for QL instruction so as to avoid teaching mathematical skills too narrowly (i.e. only for use in everyday life). Bringing developmental mathematics and discipline-based instruction closer together may increase the capacity of students to apply mathematical skills in meaningful ways during subsequent academic tasks. One way to accomplish this would be to use authentic materials, such as the textbooks used in college science courses, during QL instruction. The content of discipline-area courses taken by large numbers of non-STEM majors (such as the physical or life sciences) would be a good starting point to look for authentic contexts. Linking QL instruction directly to authentic content area applications that students will encounter in a disciplinary course may increase the likelihood that students make connections between academic experiences.
2. Maintain the emphasis that currently exists in QL courses on data analysis and representation, provide more opportunities for students to engage in both formal and informal reasoning about covariation, and consider the role of geometric and spatial reasoning in QL courses. These components should be re-visited throughout a QL course, appearing as horizontal strands running throughout the semester. For example, rather than a multi-day lesson on inverse variation using one context (personal finance), this topic should appear throughout a QL course in various contexts (at least some of which should be taken directly from other academic courses). In this way, students will have opportunities to build on their developing knowledge, and to see each component in a variety of guises. Such an approach could mitigate the effects of content-specificity on student learning in QL courses.

Recommendations for Improving General Education Science Courses

The present study highlights the perspectives, and important strengths that, students whose placement scores originally put them in the lowest levels of mathematics courses, bring to the science classroom. Unfortunately, instruction for such students can tend to focus on their weaknesses rather than their strengths. The science instructors in this study reported strong perceptions that many of their students were mathematically underprepared for the study of science, and that this perception affected the choice of science tasks they employed in class. To help tap into student strengths and better connect science instruction with students' other quantitative experiences, the conclusions of this dissertation suggest the following recommendations:

1. Create conditions for interdisciplinary collaboration, so that instructors of developmental mathematics and general science courses can familiarize each other with their curricula, learning objectives, and student outcomes. This would give science instructors greater awareness of the kinds of mathematical competencies they can expect from incoming students. Of course, such an effort would require substantial time and resources, including the participation of the many part-time instructors who teach the majority of developmental mathematics courses (including QL courses) in community colleges.
2. Identify the similarities and differences in the language and methods used by science and mathematics instructors, so as to advance mutual understanding. Such work would help science instructors avoid re-inventing the wheels that mathematics instructors have already invented, and help mathematics instructors understand how to better mathematize and make sense of scientific. A shared language is also valuable because it gives students a consistent experience across quantitative courses.

3. Emphasize the cognitive aspects of problem solving (e.g. the levels of QL-demand) when implementing science tasks. Training students to recognize and process different types of quantitative thinking while studying science may allow instructors to more effectively implement tasks that involve higher-order thinking. A greater focus on the quality of mental processes, as well as the production of technically correct answers, should be our measures of educative growth.
4 General science instructors would do well to emphasize the quantitative aspects of their disciplines. Such an emphasis on the quantitative aspects of science has the potential to push students down a path toward making quantitative reasoning part of their academic tool-kit for the remainder of their lives.

Recommendations for Further Research

As Mesa (2007) noted, there is little research on the relationship on how mathematics instruction fits in the larger scheme of student learning in community colleges. Therefore, the field is ripe with potential studies. Regarding further studies in the field of quantitative literacy, and in particular with respect to the role of QL in science education, the conclusions of this study suggest the following recommendations:

1. Based on the limitations of this study, and to help correct for researcher bias, a survey of a large sample of general education science instructors and students should be conducted to assess the extent to which different mathematical/statistical components of quantitative literacy appear in such courses. Similarly, the survey should inquire as to the representation of different QL-demand levels in science courses, to see if the same or similar findings would be uncovered.

2. A further study, under similar conditions, should be undertaken among QL students who subsequently enrolled in a wider variety of courses, such as principles of finance, sociology, anthropology, marketing, and philosophy. The results of such a study could then be compared to, and contrasted with, the results of this study on students enrolled in general education science courses.
3. A comparison and analysis of research should be conducted to assess the subsequent academic experiences of students who take more traditional mathematics courses (e.g. College Algebra) and those who take QL courses. This research could be used to uncover similarities and/or differences in student perceptions of the quantitative literacy demands of science, as well as their relative abilities to make connections between mathematics contexts and science tasks.
4. A longitudinal study of student performance on specific science tasks (perhaps those involving algebraic reasoning) should be conducted to compare and contrast the experiences of students who take traditional developmental mathematics courses with those who take QL courses. This research would push us to move beyond student perceptions in assessing the value added by taking a QL course. In short, such a study would improve our ability to assess and evaluate the effects of QL instruction in preparing students for further academic study.

Researcher Reflections

I began this study with a notion that quantitative literacy is a bridge to further learning. This notion stood in contrast to a very real perception among students that mathematics is simply a barrier to be overcome. During some early research and experiences surrounding QL courses, I began to hear that such courses might be a better way to get students over the barrier. When I read several reports in which the success of QL courses was reported in terms of the percent of students who passed them, I became uneasy. For me, a QL course should not an obstacle that students overcome, but a place where they can refine their abilities to think and reason. Such skills should then serve them well in subsequent coursework, as well as in non-academic situations. Pass rates will continue to be an important metric in assessing the efficacy of QL courses, but in this study I wanted to find a different way to describe the role a QL course played in the academic experiences of community college students. In the process of conducting the study, I was honored to spend time talking with several talented students and instructors. As expected, the science instructors who participated in this study seemed genuinely concerned about helping students learn, and the students impressed me with their thoughtfulness, insights, and evident desire to learn. The future of these students seems bright. As the field considers how best to serve students who place into developmental mathematics courses, we are reminded once again of the words of Lynn Steen (2001), that there is indeed a case for quantitative literacy.

APPENDICES

APPENDIX A: STUDENT AND INSTRUCTOR TASK DESCRIPTIONS

Legend:

Level of QL-Demand
K: Knowing **ID**: Identifying and distinguishing **DM**: Deriving meaning
AMT: Applying mathematical techniques **HOT**: Higher-order thinking
Mathematical/Statistical Components
A: Algebraic reasoning **D**: Data analysis and representation
G: Spatial/Geometric reasoning **N**: Basic numeracy
U: Reasoning about chance and uncertainty
Type of Student Connection
S: Spontaneous **P**: Prompted **N**: None **I**: Incorrect

N/A: Participant did not provide a description for this task

Table 9.
Summary of geology task descriptions

	Task Name	Highest QL-Demand Level in Student Description	Highest QL-Demand Level in Instructor Description	Math/Stats Components in Student Description	Math/Stats Components in Instructor Description	Type of Student Connection to Quantway Task
1	Global topography	DM	DM	D, N	D, N	S
2	Glacial movement	AMT	AMT	A, N	A, D	P
3	Volume versus density	ID	K	G, N	N	
4	Basketball model of Earth	AMT	N/A	G, N	N/A	P
5	Atlantic seafloor spreading	AMT	AMT	A, D	A, D	
6	Igneous rock classification	AMT	ID	D, N	D, N	P

Table 9 (cont'd)

	Task Name	Highest QL-Demand Level in Student Description	Highest QL-Demand Level in Instructor Description	Math/Stats Components in Student Description	Math/Stats Components in Instructor Description	Type of Student Connection to Quantway Task
7	Radiocarbon dating	AMT	AMT	D, N, U	A, D, N, U	P
8	Magnetic declination	AMT	AMT	A, D, G	A, D	N
9	Hundred-year flood	HOT	DM	U	U	
10	Topographic profile construction	HOT	HOT	D	D	
11	Velocity of river through a gorge	K	K	A	A, D	P
12	Temperature, pressure, depth of geologic formations	DM	N/A	D, N	N/A	S
13	Reading contour maps (isolines)	DM	DM	D	D	
14	Isostacy	DM	N/A	A, G, N	N/A	

Table 10.
Summary of astronomy task descriptions

	Task Name	Highest QL-Demand Level in Student Description	Highest QL-Demand Level in Instructor Description	Math/Stats Components in Student Description	Math/Stats Components in Instructor Description	Type of Student Connection to Quantway Task
1	Main sequence of stars	*Gary:* DM *Erica:* DM	DM	*Gary:* A, D *Erica:* D	A, D	*Gary:* S *Erica:* P
2	Universal gravitation	*Gary:* AMT *Erica:* AMT	AMT	*Gary:* A, D, N *Erica:* A, D, N	A	*Erica:* P
3	Brightness, distance, and luminosity	*Gary:* AMT *Erica: ID*	ID	*Gary:* A, D, N *Erica:* A, D	A, D	*Gary:* S *Erica:* P
4	Wien's law (graph)	*Gary:* DM *Erica:* DM	DM	*Gary:* D *Erica:* D	D	*Gary:* N *Erica:* N
5	Wien's law (equation)	*Gary:* * *Erica:* *	AMT	*Gary:* A, N *Erica:* A	A	*Gary:* N *Erica:* N
6	Speed versus velocity	*Gary:* K *Erica:K*	K	*Gary:* G, N *Erica:* G	G, N	
7	Practicing scientific notation	*Gary:* K *Erica: ID*	ID	*Gary:* N *Erica:* N	N	*Gary:* I
8	Orbits of Planets	*Gary:* N/A *Erica:* DM	DM	*Gary*: N/A Erica: G	G	
9	Gravity on a satellite	*Gary*: N/A *Erica:* AMT	AMT	*Gary*: N/A *Erica:* N, A	A	
10	Star mapping task	*Gary:* AMT *Erica:* HOT	AMT	*Gary:* D, G, N *Erica:* D, N	D	

Table 10 (cont'd)

	Task Name	Highest QL-Demand Level in Student Description	Highest QL-Demand Level in Instructor Description	Math/Stats Components in Student Description	Math/Stats Components in Instructor Description	Type of Student Connection to Quantway Task
11	The sensitive solar system	*Gary:* N/A *Erica:HOT*	HOT	*Gary:* N/A *Erica:* A, D	D, A	
12	Extra-terrestrial life	*Gary:* * *Erica:* HOT	AMT	*Gary:* A *Erica:* N, P	N, P	
13	Model of a light wave	*Gary: ID* *Erica:* N/A	DM	*Gary:* D, G *Erica:* N/A	D	*Gary:* I

*Student's description of task was insufficient to code for this category

Table 11.
Summary of human anatomy and physiology task descriptions

	Task Name	Highest QL-Demand Level in Student Description	Highest QL-Demand Level in Instructor Description	Math/Stats Components in Student Description	Math/Stats Components in Instructor Description	Type of Student Connection to Quantway Task
1	Phases of muscle twitch response	DM	DM	D	D, N	S
2	Shapes of muscles	HOT	DM	A, G	A, G	
3	Differences in twitch response times	DM	DM	D, N	A, D, N	
4	Length-tension relationship in muscles	DM	DM	A, D	A, D, G, N	P
5	Ohm’s law	DM	ID	A, N	A, N	P
6	Action potential	DM	AMT	D	D, G	
7	Electro-magnetic spectrum	N/A	DM	N/A	A, D	N

Table 12.
Summary of "The Cell" task descriptions

	Task Name	Highest QL-Demand Level in Student Description	Highest QL-Demand Level in Instructor Description	Math/Stats Components in Student Description	Math/Stats Components in Instructor Description	Type of Student Connection to Quantway Task
1	Calorie counting	AMT	AMT	A, N	A, N	P
2	Magnification of an image	DM	DM	G	G, N	P
3	Mortality rate and life expectancy	AMT	AMT	D	A, D, N, U	P
4	Basal metabolic rate	AMT	AMT	D	A, D, N	I
5	Surface are to volume ratio of cells	N/A	ID	N/A	G	N
6	Hexagonal packing of cells	N/A	K	N/A	G	
7	Eye color and genes	HOT	AMT	U	U	P
8	Critically reading science articles	ID	ID	N	D, N, U	P
9	Body mass index	AMT	AMT	A, D, G	A, D, N	
10	Phylogenetic trees	N/A	ID	N/A	D, U	N
11	pH scale	N/A	K	N/A	A, N	

Table 13.
Summary of geography task descriptions

	Task Name	Highest QL-Demand Level in Student Description	Highest QL-Demand Level in Instructor Description	Math/Stats Components in Student Description	Math/Stats Components in Instructor Description	Type of Student Connection to Quantway Task
1	Relative versus absolute humidity	DM	ID	N	A, N	P
2	Changes in air pressure due to elevation	AMT	N/A	A	N/A	S
3	Scale on maps	DM	ID	G	G	P
4	Global mean temperatures since 1880	DM	ID	A, D, U	A, D, N, U	
5	Global warming predictions	HOT	HOT	A, D, U	A, D, U	S
6	Global topography	AMT	AMT	N	D, G, N	P
7	One-hundred year flood	HOT	DM	U	U	N
8	Representing a 3D world on a 2D map	ID	N/A	G	N/A	
9	Significant figures tutorial	ID	K	N	N	P
10	Angle of sun's rays due to latitude	HOT	DM	D, G	D, G	

Table 13 (cont'd)

	Task Name	Highest QL-Demand Level in Student Description	Highest QL-Demand Level in Instructor Description	Math/Stats Components in Student Description	Math/Stats Components in Instructor Description	Type of Student Connection to Quantway Task
11	Latitude, longitude, and location	DM	DM	D, G	D, G	
12	Composition of atmosphere	DM	DM	A, D	A, D, N	P
13	Mapping pressure with isobars	AMT	DM	N	D, N	
14	Oceans, seas, and surface area	DM	DM	D, G, N	D, G, N	P

APPENDIX B: DEMOGRAPHIC SURVEY (STUDENTS)

Thank you for your interest in participating in this study. Please complete the survey below and return it to Abe Edwards at edwar491@msu.edu.

The information collected in this survey is completely confidential, and will only be used for the purposes of this research study. No reports will ever link your real name to this demographic information.

1. My gender is: _____ Female _____ Male

2. My age is: _______

3. My race/ethnicity is:
______ White
______ African American
______ Asian
______ Hispanic
______ Native American
______ Other
Explain (optional):

4. Please list all previous math courses you have taken *since high school*

5. Please list all courses you are enrolled in for Fall 2015 (including lecture and lab sections)

6. What program are you enrolled in (if any)?

7. What are your career plans (if known)?

Thank you for completing this questionnaire. Your time and participation are greatly appreciated, and will contribute to our growing understanding of quantitative literacy courses for community college students.

APPENDIX C: DEMOGRAPHIC SURVEY (INSTRUCTORS)

Thank you for your interest in participating in this study. Please complete the survey below and return it to Abe Edwards at edwar491@msu.edu.

The information collected in this survey is completely confidential, and will only be used for the purposes of this research study. No reports will ever link your real name to this demographic information.

1. My gender is: _____ Female _____ Male

2. My age is: _______

3. My race/ethnicity is:
   ______ White
   ______ African American
   ______ Asian
   ______ Hispanic
   ______ Native American
   ______ Other
   Explain (optional):

4. What is your job title at this institution (e.g. "Assistant Professor of Biology")?

5. How long have you been teaching at this institution?

6. Please list all the courses you currently teach at this institution, and the number of years you have been teaching each course (including 2015-2016).

Thank you for completing this questionnaire. Your time and participation are greatly appreciated, and will contribute to our growing understanding of quantitative literacy courses for community college students.

APPENDIX D: CODING SCHEME DEVELOPMENT CHART

Table 14.

Coding scheme development chart

Developmental Phases of Analytic Framework	Explanation and Description of Resulting Changes to Coding Scheme
(1) Coding scheme version April 2015. After conducting reviews of relevant literature, the researcher developed an initial literature-based coding framework for a pilot study	This was a coding scheme based on the researcher's initial ideas about a conceptual framework. It featured (a) fine-grained codes for mathematical/statistical components based on the Quantway curriculum, and (b) six levels of QL-demand from Frith & Prince (2009). At the outset, the original scheme contained 52 codes.
(2) Coding scheme version July 2015. After analyzing pilot data, and discussions with colleagues and faculty, the researcher developed a revised conceptual framework and related coding scheme for the dissertation proposal.	Analysis of data revealed that some of the mathematical/statistical categories were too broad (e.g. geometric reasoning, which had only 1 code) and others were too fine-grained (e.g. basic numeracy, which included both "recognize percents in context", and "interpret percentages in context". This modified scheme contained 46 codes.
(3) Coding scheme version September 2015. After completing the instructor interviews, an initial pass through that data, conversations with faculty, and further review of literature, the coding scheme from the proposal was expanded.	Instructor interviews and additional review of literature suggested a new conceptual category related to the QL components students/instructors might perceive in the course. This category was based on Barnette & Ceci's (2002) idea that transfer is mediated by *type of information* "specific fact", "general procedure", "problem-solving strategy"). As a result, three codes were added to the scheme, bringing the total to 49 codes.
(4) Coding scheme version November 2015. After initial analysis of data from the first round of student interviews, and conversations with faculty, the coding scheme was refined and contracted.	Analysis of instructor interviews and the first round of student interviews revealed a significant issue with the "modeling" category of the mathematical/statistical components. Based on further review of literature, and conversations with faculty, the modeling codes were first compressed, and then distributed across the other categories. In addition, the Ceci & Barnett codes for *type of information* were eliminated, as they did not seem to be closely related to the study research questions. The resulting scheme contained 46 codes

Table 14 (cont'd)

Developmental Phases of Analytic Framework	Explanation and Description of Resulting Changes to Coding Scheme
(5) Coding scheme version January 2016. After further analysis of student interview and focus group data, and discussion with faculty and colleagues, the coding scheme was enriched and expanded to its final form.	Analysis of student data revealed an entirely new dimension for analysis, the ways in which students make connections between tasks in different courses. After discussion with faculty, and a work-in-progress public presentation, I added four codes in the category "Type of Connection". Additional minor modifications to the list of mathematical/statistical components (in the category *reasoning about chance and uncertainty*). Removal of the "Expressing Quantitative Concepts" level from the framework resulted in a loss of 2 codes. Final coding scheme contains 48 individual codes across 14 broad coding categories.

APPENDIX E: STUDENT INTERVIEW PROTOCOL - ROUND ONE

"Good afternoon (evening). Thank you for taking the time to discuss quantitative literacy at [Community College].

My name is Abe Edwards and I am conducting research on quantitative literacy here at [Community College]. In particular, I hope to learn which parts of the Quantway course have been beneficial to you in your other courses.

I want to talk with you about your experiences as a student who completed Quantway. In particular, I will be asking you about how that course has helped you in your other courses here at [Community College].

Before we begin, let me just suggest some things to make our discussion more productive. With your permission, I will be recording this discussion for an accurate record. It is important that I hear all of your comments, so please speak up, and be as honest and reflective as possible. No reports will ever link what you say to your name, and no one here at [Community College] will even know that you participated in these discussions. In this way, I will work to maintain your confidentiality.

If it is OK with you, I will turn on the recorder and start now.

[Start Recording]

This interview is being conducted as part of a study on quantitative literacy at [Community College]. My name is Abe Edwards and today is [Today's Date].

I I'd like to begin by simply getting some background information. Please say how you came to be a student at [Community College], what program you are in, and what you hope to do after you finish.

Other than Quantway, which math courses have you taken at [Community College]?

What courses are you enrolled in this semester?

I am really interested to know if the things you studied in Quantway have come up again in your [Name of Science Course] this semester. To help get the conversation going, I will give you some specific tasks from Quantway that I hope you remember. We'll talk about each task briefly, and then I will ask you if you can think of anything you've done in your science course that you think is similar to the Quantway lesson. I know it's early in the semester, so if you can't think of any particular science lesson, that's fine.

II. Let's begin with *Basic Numeracy*. Now, in Quantway, you had this lesson [Handout 1] on the percent of men and women who smoke on college campuses. Do you remember this lesson?

Probe: What can you tell me about this lesson? What did you have to do to complete it?

In this lesson you covered topics such as converting from ratios to percents and using a reference value. You might have had to convert from decimals to percents, use scientific notation, or calculate percent increase or decrease. Let's think about your science course for a minute.

Can you think of anything you've done in your science course this semester that used this kind of math?

> *Probe: [If student speaks in general terms, as for a specific instance in the science course]*
>
> *Probe: [If student fails to mention a task and the Instructor cited a clear example in the course] While preparing for this interview, I noticed a problem from the textbook [lab manual], here on page [Page #]. Do you cover this problem in class?*

What did you have to do to complete this task in your science course?

Do you think there is any connection between this science task and this Quantway task?

> *Probe: What can you tell me about how they are similar?* OR *What do you think is different about these two tasks?*

III. Let me ask about another mathematical category, *Algebraic Reasoning*. Now, in Quantway, you had this lesson [Handout 2] on the factors associated with the costs of car ownership. Do you remember this lesson?

Probe: What can you tell me about this lesson? What did you have to do to complete it?

In this lesson you had to make some assumptions about the real-life situation, decide, come up with a linear function relating purchase cost, daily expense, and total cost of ownership, and then describe how the cost was either directly or inversely proportional to the different factors.

Can you think of anything you've done in your science course this semester that used this kind of math?

> *Probe: [If student speaks in general terms, as for a specific instance in the science course]*
>
> *Probe: [If student fails to mention a task and the Instructor cited a clear example in the course] While preparing for this interview, I noticed a problem from the textbook [lab manual], here on page [Page #]. Do you cover this problem in class?*

What did you have to do to complete this task in your science course?

Do you think there is any connection between this science task and this Quantway task?

> *Probe: What can you tell me about how they are similar?* OR *What do you think is different about these two tasks?*

IV. The next category is *Data Analysis and Representation.* Now in Quantway, you had this lesson [Handout 3] on homelessness in different parts of the country. Do you remember this lesson?

> *Probe:* What can you tell me about this lesson? What did you have to do to complete it?

In this lesson you had to read and interpret graphs and tables, and take information from a table and create your own graphs.

Can you think of anything you've done in your science course this semester that used this kind of math?

> *Probe: [If student speaks in general terms, as for a specific instance in the science course]*

> *Probe: [If student fails to mention a task and the Instructor cited a clear example in the course] While preparing for this interview, I noticed a problem from the textbook [lab manual], here on page [Page #]. Do you cover this problem in class?*

What did you have to do to complete this task in your science course?

Do you think there is any connection between this science task and this Quantway task?

> *Probe: What can you tell me about how they are similar?* OR *What do you think is different about these two tasks?*

V. The next category is *Spatial and Geometric Reasoning*. In Quantway, you had this lesson [Handout 4] on finding the costs associated with fertilizing someone's yard. Do you remember this lesson?

Probe: What can you tell me about this lesson? What did you have to do to complete it?

In this lesson you had to calculate areas and perimeters, make estimates based on different shapes, and think about the scale of different sizes of objects.

Can you think of anything you've done in your science course this semester that used this kind of math?

Probe: [If student speaks in general terms, as for a specific instance in the science course]

Probe: [If student fails to mention a task and the Instructor cited a clear example in the course] While preparing for this interview, I noticed a problem from the textbook [lab manual], here on page [Page #]. Do you cover this problem in class?

What did you have to do to complete this task in your science course?

Do you think there is any connection between this science task and this Quantway task?

Probe: What can you tell me about how they are similar? OR *What do you think is different about these two tasks?*

VI. This will be the last category for today, and thanks for your patience. This category is *Chance and Uncertainty*. Now in Quantway, you had this lesson [Handout 5] on the probabilities associated with medical testing. Do you remember this lesson?

Probe: What can you tell me about this lesson? What did you have to do to complete it?

In this lesson you had to calculate different probabilities, and interpret what the different probabilities meant. But you also had to do some converting from percents to probabilities, and use different graphics to interpret probabilities.

Can you think of anything you've done in your science course this semester that used this kind of math?

Probe: [If student speaks in general terms, as for a specific instance in the science course]

Probe: [If student fails to mention a task and the Instructor cited a clear example in the course] While preparing for this interview, I noticed a problem from the textbook [lab manual], here on page [Page #]. Do you cover this problem in class?

What did you have to do to complete this task in your science course?

Do you think there is any connection between this science task and this Quantway task?

Probe: What can you tell me about how they are similar? OR *What do you think is different about these two tasks?*

VII. Those are the main categories that I was hoping to talk about, but is there any mathematics or statistics from Quantway that we haven't discussed that you've noticed in your science course?

VIII. I want to shift gears for my final questions. And really, since it is early in the semester, this is just something to be thinking about over the upcoming weeks. [Handout 6]. One way to think about QL is by describing certain techniques, which is pretty much what we've done so far. But another way is to ask about the kinds of *thinking* you have to do to complete a task. Such thinking can range from very simple knowing, or identifying, all the way up to reflecting, evaluating, or conjecturing.

I would like you to think about a task from your science course that you believe required you to use some higher-order thinking. Maybe even something we've discussed today. Can you describe any task where you had to do these things [*refer to Frith & Prince description*]

> *Probe: What was it about this task that made you choose it? What did you have to do to complete the task?*

Finally, I would like you to think about a task from your science course that you believe *did not* require any higher-order thinking. Maybe even something we've discussed today. Can you describe any task where only had to use these lower levels of thinking [*refer to Frith & Prince description*]?

> *Probe: What was it about this task that made you choose it? What did you have to do to complete the task?*

IX. That's about all the time we have today, but I want to say thank you so much for all your help. I think your perspective is really going to be valuable for this study.

Is there anything we left out, or that you did not get a chance to say?

Thank you again for taking the time to participate in this discussion.

APPENDIX F: STUDENT INTERVIEW PROTOCOL - ROUND TWO

"Good afternoon (evening). Thank you for taking the time to discuss quantitative literacy at [Community College].

My name is Abe Edwards and I am conducting research on Quantitative Literacy here at [Community College]. In particular, I hope to learn which parts of the Quantway course have been beneficial to you in your other courses.

I want to talk with you about your experiences as a student who completed Quantway. In particular, I will be asking you about how that course has helped you in your other courses here at [Community College].

Before we begin, let me just suggest some things to make our discussion more productive. With your permission, I will be recording this discussion for an accurate record. It is important that I hear you, so please speak clearly, and be as honest and reflective as possible. No reports will ever link what you say to your name, and no one here at [Community College] will even know that you participated in these discussions. In this way, I will work to maintain your confidentiality.

If it is OK with you, I will turn on the recorder and start now.

[Start Recording]

This interview is being conducted as part of a study on quantitative literacy at [Community College]. My name is Abe Edwards and today is [Today's Date].

As you may recall from the last time we met, the goal of this research is to discover which, if any, components of your quantitative literacy course have re-appeared in your [name of course]. The last time we met, you gave me some great information, but many weeks have passed since then. I'm interested to see what else you've noticed. As with our first interview, I am going to remind you of some specific lessons from Quantway. I'll then ask you to think if any of the math from those lessons has re-appeared in your [Science Course]. I may probe for specific examples, or ask you to elaborate on specific mathematical components. But feel free to share anything that comes to mind. Do you have any questions before we begin?

I. Let's begin with *Basic Numeracy*. For example, in Quantway, you had this lesson [Handout 1] on the breakdown, by percent, of federal government spending.

What can you tell me about this lesson? What did you have to do to complete it?

In that lesson you covered mathematics such as absolute percents and cumulative percent, but you also had to do some basic arithmetic, and conversions. You also had to deal with some really large numbers. Let's think about your science course for a minute. Can you think of anything you've done in your science course this semester that used this kind of math?

> *Probe: [If student speaks in general terms, as for a specific instance in the science course]*

> *Probe: [If student fails to mention a task and the Instructor cited a clear example in the course] While preparing for this interview, I noticed a problem from the textbook [lab manual], here on page [Page #]. Do you cover this problem in class?*

What did you have to do to complete this task in your science course?

Do you think there is any connection between this science task and this Quantway task?

> *Probe: What can you tell me about how they are similar?* OR *What do you think is different about these two tasks?*

III. Let me ask about another mathematical category, *Algebraic Reasoning*. In Quantway you had this lesson [Handout 2] on selling t-shirts. Do you remember this lesson?

What can you tell me about this lesson? What did you have to do to complete it?

This kind of thinking includes more than just solving for x and y, right? It also includes contexts like "if I change the value of one variable in an equation, what effect does this have on another variable?" For example, there was a direct relationship between the number of t-shirts sold and income. But there was an inverse relationship between price of t-shirt and the number sold.

Can you think of anything you've done in your science course this semester that used this kind of math?

> *Probe: [If student speaks in general terms, as for a specific instance in the science course]*

> *Probe: [If student fails to mention a task and the Instructor cited a clear example in the course] While preparing for this interview, I noticed a problem from the textbook [lab manual], here on page [Page #]. Do you cover this problem in class?*

What did you have to do to complete this task in your science course?

Do you think there is any connection between this science task and this Quantway task?

> *Probe: What can you tell me about how they are similar?* OR *What do you think is different about these two tasks?*

IV. The next category is *data analysis and representation.* In Quantway, you had this lesson [Handout 3] on child abuse and links to homelessness. Do you recall this lesson?

What can you tell me about this lesson? What did you have to do to complete it?

Some of the math involved in this lesson included correlation, causation, matching a line to a scatter plot, and interpreting graphs of data.

Can you think of anything you've done in your science course this semester that used this kind of math?

> *Probe: [If student speaks in general terms, as for a specific instance in the science course]*
>
> *Probe: [If student fails to mention a task and the Instructor cited a clear example in the course] While preparing for this interview, I noticed a problem from the textbook [lab manual], here on page [Page #]. Do you cover this problem in class?*

What did you have to do to complete this task in your science course?

Do you think there is any connection between this science task and this Quantway task?

> *Probe: What can you tell me about how they are similar?* OR *What do you think is different about these two tasks?*

V. Another mathematical category we're interested in is *Spatial or Geometric Reasoning*. In Quantway you had this lesson [Handout 4] on the Great Pacific Garbage Patch. Do you remember this lesson?

What can you tell me about this lesson? What did you have to do to complete it?

This lesson had a lot of scaling in it. You had to basically make a scale model of a real-life situation, you had to use some basic geometry formulas, and even make some predictions based on the geometry of the situation.

Can you think of anything you've done in your science course this semester that used this kind of math?

> *Probe: [If student speaks in general terms, as for a specific instance in the science course]*
>
> *Probe: [If student fails to mention a task and the Instructor cited a clear example in the course] While preparing for this interview, I noticed a problem from the textbook [lab manual], here on page [Page #]. Do you cover this problem in class?*

What did you have to do to complete this task in your science course?

Do you think there is any connection between this science task and this Quantway task?

> *Probe: What can you tell me about how they are similar?* OR *What do you think is different about these two tasks?*

VI. This will be the last category for today, and thanks for your patience. This category is *reasoning about chance and uncertainty.* In Quantway, you had this lesson [Handout 5] on basketball free-throws. Do you recall this lesson?

What can you tell me about this lesson? What did you have to do to complete it?

This lesson was primarily about conditional probabilities, but you had to make predictions, interpret two-way tables, and think about dependent vs. independent events.

Can you think of anything you've done in your science course this semester that used this kind of math?

> *Probe: [If student speaks in general terms, as for a specific instance in the science course]*

> *Probe: [If student fails to mention a task and the Instructor cited a clear example in the course] While preparing for this interview, I noticed a problem from the textbook [lab manual], here on page [Page #]. Do you cover this problem in class?*

What did you have to do to complete this task in your science course?

Do you think there is any connection between this science task and this Quantway task?

> *Probe: What can you tell me about how they are similar?* OR *What do you think is different about these two tasks?*

VII. Those are the main categories that I was hoping to talk about, but is there any mathematics or statistics from Quantway that we haven't discussed that you've noticed in your science course?

VIII. Let me shift gears for my final questions. In our first meeting, we briefly talked about levels of quantitative literacy demand [Handout 6]. Do you remember talking about these?

In any task, you might have to engage with multiple levels. You might have to do some reading and interpreting, some deriving meaning, maybe even some higher order thinking. Think back to different tasks in your [Science course], even the activities you mentioned today. Are you able to describe a problem where you had to use some higher-order thinking?

> *Probe: What was it about this task that made you choose it? What did you have to do to complete the task?*

Finally, I would like you to think about a task from your science course that you believe *did not* require any higher-order thinking. Maybe even something we've discussed today. Can you describe any task where only had to use these lower levels of thinking [*refer to Frith & Prince description*]?

> *Probe: What was it about this task that made you choose it? What did you have to do to complete the task?*

IX. That's about all the time we have today, but I want to say thank you so much for all your help. I think your perspective is really going to be valuable for this study.

Is there anything we left out, or that you did not get a chance to say?

Thank you again for taking the time to participate in this discussion.

APPENDIX G: FOCUS GROUP PROTOCOL

"Good afternoon (evening). Thank you for taking the time to join our discussion of quantitative literacy at [Community College].

My name is Abe Edwards and I am conducting research on Quantitative Literacy here at [Community College]. I want to talk with you about your experiences as students who have completed Quantway, and the extent to which it has been helpful in your current science courses.

Before we begin, let me suggest some things to make our discussion more productive. I will be recording this discussion for an accurate record, but your real names will be deleted from any written transcripts or research reports. It is important that we hear all of your comments, so please speak up, and only speak one at a time. We'll only use first names here. No reports will ever link what you say to your name, and no one here at [Community College] will even know that you participated in these discussions. In this way, I will work to maintain your confidentiality. I would ask that you respect the confidentiality of others, by not repeating what people say outside of this room.

During the next hour, I will ask you questions, and I will listen carefully to what you have to say. I will not really participate in the discussion. So please, feel free to respond to each other and to speak directly to others in the room. You don't need to raise your hand, or wait to be called on to speak.

I really want to hear from all of you. I am interested in both your experiences, and your opinions. If you are pretty quiet during the discussion, I might act as a traffic cop and encourage you to speak, while asking the others to remain quiet for a short time.

If it is OK with you, I will turn on the recorder and start now.

[Start Recording]

This focus group is being conducted as part of a study on quantitative literacy at [Community College]. My name is Abe Edwards, and I am the moderator of this discussion.

I. Let's begin with introductions. Please tell us your first name, what program you are in, and what courses you are currently taking here at [Community College].

II. I am really interested to know which of the things you learned in Quantway have been beneficial to you in your other classes. To help get the conversation going, I will ask about some specific mathematical topics, and if you think of other parts of the course that were really useful, you can talk about those, as well.

To refresh your memories of the kinds of things you did in Quantway, I have created a list of the learning goals for that course. We can refer to it during our discussion if that would be helpful [Pass out Handout of Learning Goals]

III. In our one-on-one interviews, some of you mentioned *[Topic related to Basic Numeracy]* [Topics for follow-up determined by initial student interviews]

Can someone share how [that topic] came up in your current science classes?

Has anyone else noticed [this topic] in your current science classes?

Has anyone noticed any similar topics in your current science classes [Refer students to list of learning goals for Numbers and Operations]

> *Probe: If more than one student mentions a topic in different classes, pursue similarities or differences in the frequency/treatment of the topic in each course.*

IV. Another topic that came up in the one-on-one interviews was *[Topic related to Algebraic Reasoning]* [Topics for follow-up determined by initial student interviews]

Can someone share how [that topic] came up in your current science classes?

Has anyone else noticed [this topic] in your current science classes?

Has anyone noticed any similar topics in your current science classes [Refer students to list of learning goals for Proportional Reasoning]

> *Probe: If more than one student mentions a topic in different classes, pursue similarities or differences in the frequency/treatment of the topic in each course.*

V. In our one-on-one interviews, some of you mentioned *[Topic related to Data Analysis and Representation]* [Topics for follow-up determined by initial student interviews]

Can someone share how [that topic] came up in your current science classes?

Has anyone else noticed [this topic] in your current science classes?

Has anyone noticed any similar topics in your current science classes [Refer students to list of learning goals for Data Analysis and Representation]

> *Probe: If more than one student mentions a topic in different classes, pursue similarities or differences in the frequency/treatment of the topic in each course.*

VI. In our one-on-one interviews, some of you mentioned *[Topic related to Spatial/Geometric Reasoning]* [Topics for follow-up determined by initial student interviews]

Can someone share how [that topic] came up in your current science classes?

Has anyone else noticed [this topic] in your current science classes?

Has anyone noticed any similar topics in your current science classes [Refer students to list of learning goals for Statistical Thinking]

> *Probe: If more than one student mentions a topic in different classes, pursue similarities or differences in the frequency/treatment of the topic in each course.*

VII. In our one-on-one interviews, some of you mentioned *[Topic related to Probabilistic Reasoning]* [Topics for follow-up determined by initial student interviews]

Can someone share how [that topic] came up in your current science classes?

Has anyone else noticed [this topic] in your current science classes?

Has anyone noticed any similar topics in your current science classes [Refer students to list of learning goals for Statistical Thinking]

> *Probe: If more than one student mentions a topic in different classes, pursue similarities or differences in the frequency/treatment of the topic in each course.*

VIII. I want to shift gears and talk about a different aspect of my research. [Hand out the framework for Quantitative Literacy Demand]. Of course we're interested in which mathematical topics have come up in your science courses, but it's also important for us to know the kinds of thinking you are had to do throughout the science course.

First, does this handout make sense to you? What questions do you have about it?

Someone mentioned [Specific Topic from earlier in the discussion]. Let's use that as our example. When [That Topic] came up, which of the things on this handout did you have to do?

How about [Another specific topic from earlier in the discussion]. Who mentioned this in your course? When you had to do that task, what kinds of thinking do you feel that you had to do?

Can anyone think of an example in your science course where you've done anything listed under *higher order thinking*?

IX. We're almost done now, and you've provided a lot of great feedback regarding the connections between Quantway and your other courses. Is there anything we left out, or that you did not get a chance to say?

Thank you again for taking the time to participate in this discussion.

APPENDIX H: INSTRUCTOR INTERVIEW PROTOCOL

"Good afternoon (evening). Thank you for taking the time to discuss your [Course Name] at [Community College]

My name is Abe Edwards and I am conducting research in mathematics education here at [Community College]. In particular, I hope to learn more about the quantitative components of your [Course Name] course. The intent of this research is really to learn more about how we can help improve the math and science experiences of [Community College] students. I am not here to evaluate or critique either your course, or yourself as an instructor.

With your permission, I will be recording this discussion for an accurate record. It is important that you feel the freedom be as honest and reflective as possible. No reports will ever link what you say to your name, and no one here at [Community College] will even know that you participated in these discussions. In this way, I will work to maintain your confidentiality.

If it is OK with you, I will turn on the recorder and start now.

[Start Recording]

This interview is being conducted as part of a study on quantitative literacy at [Community College]. My name is Abe Edwards and today is [Today's Date].

I. I'd like to begin by simply getting some background information. Please say how you came to be an instructor at [Community College], how long you have been here, and what courses you currently teach.

Today, we're discussing your [Course Name] course. How long have you been teaching this course?

Which textbook are you using for this course? Can you tell me approximately how far you hope to cover in the book?

Do you use any other resources for this course, such as a lab manual?

I am really interested to know what kinds of mathematics, or other quantitative skills, students encounter in your class. For convenience, I have grouped some potential mathematical topics according to five broad categories [Provide Handout 1]. I'd like to talk about these one at a time, and then you can add anything else that doesn't appear to fit this list.

II. Let's begin with *Basic Numeracy*. Now, in a math course, we might ask students to convert from decimals to percents, use scientific notation, or calculate percent increase or decrease. But other topics, like orders of magnitude, also fall into this category. Here is a more detailed list of components [Refer to Handout 1, section on Basic Numeracy]. As you think about your science course, do any tasks stand out as requiring these types of quantitative skills?

> *Probe: [Depending on the specific course, prompt for a reasonable context in which such topics might appear]*

Can you give me a specific task (assignment/activity) in which students would have to use this kind of mathematics?

What do you want the students to be able to do during, or as a result of, this task?

> *Probe: Can you give me any more examples of tasks from your course that involve this kind of mathematics?*

III. Let me ask about another mathematical category, *Algebraic Reasoning*. This includes more than just solving for *x* and *y*, it also includes creating or using equations in one or more variables, working with direct or inverse variation, and many other things. Here is a more detailed list of components [Refer to Handout 1, section on Algebraic Reasoning].
As you think about your science course, do any tasks stand out as requiring these types of quantitative skills?

> *Probe: [Depending on the specific course, prompt for a reasonable context in which such topics might appear]*

Can you give me a specific task (assignment/activity) in which students would have to use this kind of mathematics?

What do you want the students to be able to do during, or as a result of, this task?

> *Probe: Can you give me any more examples of tasks from your course that involve this kind of mathematics?*

IV. The next category I'd like to discuss is *data analysis and representation*. This includes both calculating and using statistics, as well as interpreting graphs, tables of data, or interpreting the results of statistical studies. Here is a more detailed list of components [Refer to Handout 1, section on Data Analysis].

As you think about your science course, do any tasks stand out as requiring these types of quantitative skills?

> *Probe: [Depending on the specific course, prompt for a reasonable context in which such topics might appear]*

Can you give me a specific task (assignment/activity) in which students would have to use this kind of mathematics?

What do you want the students to be able to do during, or as a result of, this task?

> *Probe: Can you give me any more examples of tasks from your course that involve this kind of mathematics?*

V. Another category we're interested in is *Geometric or Spatial Reasoning*. This includes using geometric formulas for perimeter, area, surface area, volume, and so on. But it also includes things like scaling, or thinking about how the geometry of space helps us make sense of the world. Here is a more detailed list of components [Refer to Handout 1, section on Data Analysis].

As you think about your science course, do any tasks stand out as requiring these types of quantitative skills?

> *Probe: [Depending on the specific course, prompt for a reasonable context in which such topics might appear]*

Can you give me a specific task (assignment/activity) in which students would have to use this kind of mathematics?

What do you want the students to be able to do during, or as a result of, this task?

> *Probe: Can you give me any more examples of tasks from your course that involve this kind of mathematics?*

VI. This will be the last category for today, so thanks for your patience. *Reasoning about chance and uncertainty*. This would include things like calculating probabilities using specific rules, thinking about conditional probability, understanding the role of uncertainty or variability, and so on. Here is a more detailed list of components [Refer to Handout 1, section on Data Analysis].

As you think about your science course, do any tasks stand out as requiring these types of quantitative skills?

> *Probe: [Depending on the specific course, prompt for a reasonable context in which such topics might appear]*

Can you give me a specific task (assignment/activity) in which students would have to use this kind of mathematics?

What do you want the students to be able to do during, or as a result of, this task?

> *Probe: Can you give me any more examples of tasks from your course that involve this kind of mathematics?*

VII. Are there any quantitative skills your course requires that we haven't mentioned?

If so, probe: Can you describe this task? What do you want the students to be able to do?

VIII. I'd like to shift gears here and think about the quantitative demands of your course in a different way. I'm going to ask you to step back and think less about specific mathematics, and more about the *levels of quantitative demand* of the tasks in your course.

If you are familiar with Bloom's taxonomy, this might look familiar (Handout 2). As you look over these levels of *quantitative demand*, can you think of tasks or experiences in your course that would require students to think at these various levels?

Probe: Can you give me an example of a task that requires some higher-order thinking?

Probe: What do you want students to be able to do in that task?

[Repeat as necessary]

Probe: Can you give me an example of a task that only requires some of the lower levels?

Probe: What do you want students to be able to do in that task?

[Repeat as necessary]

IX. That's about all the time we have today, but I want to say thank you so much for all your help. I think your perspective is really going to be valuable for this study.

Is there anything we left out, or that you did not get a chance to say?

Thank you again for taking the time to participate in this discussion.

APPENDIX I: INFORMED CONSENT FORM

1. EXPLANATION OF THE RESEARCH and WHAT YOU WILL DO:
    - You are being asked to participate in a research study of connections between a quantitative literacy course “Quantway” and general education science courses at [Community College].
    - In order to participate in this research, you agree to participate in at least one individual interview with a researcher about your experiences with quantitative literacy in your course(s). You will also be asked to complete a short demographic survey. For students, you also agree to participate in a small-group interview about your experiences with both Quantway and your general science courses.
    - You must be at least 18 years old to participate in this research.

2. YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW:
    - Participation in this research project is completely voluntary. You have the right to say no. You may change your mind at any time and withdraw. You may choose not to answer specific questions or to stop participating at any time.
    - For students, whether you choose to participate or not will have no affect on your grade or evaluation in Quantway, or any other course. Your instructors will not know who, if anyone, participates in this research.

3. COSTS AND COMPENSATION FOR BEING IN THE STUDY:

Points to include:
- Immediately upon completion of each interview, you will be given a $50 VISA gift card. Students who participate in multiple interviews will be given a $50 VISA gift card *per interview*.

4. CONTACT INFORMATION FOR QUESTIONS AND CONCERNS: **(Investigator contact information is necessary; HRPP contact info is NOT required for EXEMPT research)**

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact: Richard Edwards, [Address]. By email at [email].

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University’s Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or email irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

5. DOCUMENTATION OF INFORMED CONSENT.

A signature is not a required element of consent for EXEMPT protocols

Your signature below means that you voluntarily agree to participate in this research study.

Signature ____ Date_________________

APPENDIX J: CODING SCHEME

1. Mathematical/Statistical QL Components in Science Tasks

Basic Numeracy

N1. Perform basic arithmetic
N2. Demonstrate understanding of magnitude (including scientific notation)
N3. Use estimation skills
N4. Demonstrate measurement sense (including units, precision, accuracy, error)
N5. Use and interpret percentages
N6. Distinguish between absolute and relative change
N7. Check the reasonableness of calculations

Algebraic Reasoning

A1. Understand the role of variables in an equation or relationship
A2. Describe the effect that a change in one variable has on the others
A3. Construct and use equations in one or more variables
A4. Recognize covariant relationships (including direct and inverse variation)
A5. Solve real world problems using the language and structure of algebra
A6. Solve real world problems using ratios and proportions

Data Analysis and Representation

D1. Compute basic statistics including measures of center and measures of spread
D2. Evaluate statistics that appear in a written report
D3. Determine sources of bias in data
D4. Describe the difference between correlation and causation
D5. Evaluate the sampling strategy used in a study
D6. Read, interpret and make decisions based on visual displays of quantitative information

Reasoning about chance and uncertainty

P1. Use the language of probability to interpret statements regarding risk or chance
P2. Apply rules of probability to solve real-life problems
P3. Recognize the presence of uncertainty in measurements, predictions, or data
P4. Interpret statements involving conditional probability
P5. Understand that mathematical models of real-life situations are subject to error

Spatial/Geometric Reasoning

G1. Solve problems involving area, perimeter, or volume
G2. Understand and translate between different units of measurement
G3. Solve problems involving geometric scaling
G4. Attend to geometric information on graphs, images, and diagrams

2. Quantitative Literacy Demand Levels of Science Tasks:

Knowing

K1. Knowing the meaning of quantitative terms and phrases (verbal representations)
K2. Knowing the conventions for the *symbolic* representation of numbers, measurements, variables and operations
K3. Knowing the conventions for the representation of quantitative information in tables, charts, graphs, diagrams, and objects.

Identifying and Distinguishing

ID1. Identifying connections and distinctions between different representations of quantitative concepts
ID2. Identifying the mathematics to be done and strategies to do it
ID3. Identifying relevant and irrelevant information in representations

Deriving Meaning

DM1. Understanding a verbal description of a quantitative concept/situation/process
DM2. Deriving meaning from representations of data in context
DM3. Deriving meaning from graphical representations of relationships
DM4. Deriving meaning from diagrammatic representations of spatial entities
DM5. Translating between different representations

Applying Mathematical Techniques

AMT Use mathematical techniques to solve a problem, or clarify understanding – for example, calculating, estimating, measuring, ordering, modeling, applying algebraic techniques, etc.

Higher Order Thinking

HOT1. Synthesizing information and ideas from more than one source
HOT2. Logical reasoning
HOT3. Conjecturing
HOT4. Interpreting, reflecting, evaluating

3. Types of Connections Made By Students

SC. Spontaneous connection. Student is given a QL task, comes up with the science task and describes a connection
PC. Prompted connection. Student is given both the QL task and the science task, and describes a connection
NC. No connection. Student is given both the QL task and the science task, and is not able to describe a connection
IC. Incorrect connection. Student describes a connection between two tasks that is mathematically inaccurate. For example, claiming that both tasks are examples of inverse variation when they are not.

APPENDIX K: SAMPLE INTERVIEW CODED FOR MATHEMATICAL/STATISTICAL COMPONENTS

Extra-terrestrial Life Task

Participant: Erica
Date: December 9, 2015
Final Codes: **[P1, P2, P3, N1, N3, N5]**

Erica: When we talked about – the last thing we talked about was like the chances of there being life somewhere else in the universe, using the probability, like the universe is so big there probably is a chance that there's some sort of life; maybe not intelligent life. But it actually takes a lot – like it has to be exact conditions for life to form because it's a really strict formula for –

IN: Strict, as in, what is necessary for life to form–

Erica: Yeah. Temperature, water, sun, heat and –

IN: Right amount of gravity so we don't –

Erica: Yeah, so it's kind of hard for that to happen but since the universe is so big, it's probably like there is something. And we just guessed at some of the percents, so it's not exact, right? But it's [the Universe] so large that when you multiply the number of planets, or whatever, you still would think there should be some life out there.

Participant: Professor Astro
Date: September 7, 2015
Final Codes: **[N1, N2, N3, N5, P1, P2]**

PA: I'm not sure they really, well maybe no one really does, but they don't understand how big the Universe really is. The sheer number of stars, planets, planetary systems–it's mind-boggling.
IN: And how do you help them make sense of that kind of scale, those numbers?
PA: Not very well! I mean, what does it mean that there are, oh, 10^{24} planets in the Universe? Who knows what that number even means?
IN: Right, is that like the number of grains of sand on a beach, or–
PA: Right. It's so big that, well, one activity I like to do with them is, especially if we have some extra time, is to think about the possibility of life existing somewhere else in the Universe.
IN: Oh, that's really interesting.
PA: Yeah, and it's a good way to help them interpret the sheer size of the Universe. Because you take your different parameters, what percent of all planets are far enough from a star to be warm enough to support life, but not too warm? What percent have the right

atmosphere? What percent have the right size? All these things. So we just put values on these parameters, and the thing is, you can make them as small as you want. Really small percentages. But when you consider the number of planets out there –well, the likelihood is actually pretty decent.

IN: Really?

PA: Absolutely. But then this gets into a discussion of aliens, and someone mentioned [the movie] Contact, and it turns into a fifteen-minute discussion. And the result is I don't get through all my slides.

Muscle Contraction Task

Participant: Kelsey
Date: November 30, 2015
Final Codes: **[D6, A4, G4]**

IN: Can you say more about what's going on here?

K: Right. This really struck me as something that made sense because of what we did in Quantway. Just being able to look at this [see Figure 7] and being able to make sense of it you know as tension goes up and time goes like this, this is a muscle contraction. I feel like I'm – can do that better because of Quantway. The maximal stimuli– this is what that looks like, so it's making sense of the vocabulary, and what it looks like on a chart or a graph. If I was to get one of these terms, and this was a graph and it wasn't labeled, and you had to circle where the, the maximal stimuli is, you know, you'd have to make sense of what that is on a graph.

APPENDIX L: SAMPLE INTERVIEW CODED FOR LEVELS OF QUANTITATIVE LITERACY DEMAND

Extra-terrestrial Life Task

Participant: Erica
Date: December 9, 2015
Final Codes: **[K1, ID2, DM1, AMT, HOT2, HOT3, HOT4]**

E: When we talked about – the last thing we talked about was like the chances of there being life somewhere else in the universe, using the probability, like the universe is so big there probably is a chance that there's some sort of life; maybe not intelligent life. But it actually takes a lot – like it has to be exact conditions for life to form because it's a really strict formula for –

IN: Strict, as in, what is necessary for life to form–

E: Yeah. Temperature, water, sun, heat and –

IN: Right amount of gravity so we don't –

E: Yeah, so it's kind of hard for that to happen but since the universe is so big, it's probably like there is something. And we just guessed at some of the percents, so it's not exact, right? But it's [the Universe] so large that when you multiply the number of planets, or whatever, you still would think there should be some life out there.

Participant: Professor Astro
Date: September 7, 2015
Final Codes: **[K1, K2, ID2, DM1, AMT, HOT2, HOT3, HOT4]**

PA: I'm not sure they really, well maybe no one really does, but they don't understand how big the Universe really is. The sheer number of stars, planets, planetary systems–it's mind-boggling.
IN: And how do you help them make sense of that kind of scale, those numbers?
PA: Not very well! I mean, what does it mean that there are, oh, 10^{24} planets in the Universe? Who knows what that number even means?
IN: Right, is that like the number of grains of sand on a beach, or–
PA: Right. It's so big that, well, one activity I like to do with them is, especially if we have some extra time, is to think about the possibility of life existing somewhere else in the Universe.
IN: Oh, that's really interesting.
PA: Yeah, and it's a good way to help them interpret the sheer size of the Universe. Because you take your different parameters, what percent of all planets are far enough from a star to be warm enough to support life, but not too warm? What percent have the right atmosphere? What percent have the right size? All these things. So we just put values on

these parameters, and the thing is, you can make them as small as you want. Really small percentages. But when you consider the number of planets out there –well, the likelihood is actually pretty decent.

IN: Really?

PA: Absolutely. But then this gets into a discussion of aliens, and someone mentioned [the movie] Contact, and it turns into a fifteen-minute discussion. And the result is I don't get through all my slides.

Muscle Contraction Task
Participant: Kelsey
Date: November 30, 2015
Final Codes: **[K3, ID1, ID3, DM1, DM2, DM3, DM5]**

IN: Can you say more about what's going on here?

K: Right. This really struck me as something that made sense because of what we did in Quantway. Just being able to look at this [see Figure 7] and being able to make sense of it you know as tension goes up and time goes like this, this is a muscle contraction. I feel like I'm – can do that better because of Quantway. The maximal stimuli– this is what that looks like, so it's making sense of the vocabulary, and what it looks like on a chart or a graph. If I was to get one of these terms, and this was a graph and it wasn't labeled, and you had to circle where the, the maximal stimuli is, you know, you'd have to make sense of what that is on a graph.

APPENDIX M: DOCUMENT SUMMARY FORM

Name of Document:

Document No.:

Date Published:

Event or Contact With Which Document Is Associated:

Specific Portion of Document Used:

Page #	**Key Words/Concepts/Images**	**Comments:**

Brief Summary of Contents:

Questions/Issues to Consider:

Additional Comments:

REFERENCES

REFERENCES

Altheide, D.L., & Johnson, J.M. (1994). Criteria for assessing interpretive validity in qualitative research. In N.K. Denzin & Y.S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 485-499). Thousand Oaks, CA: Sage Publications.

Apter, A. J., Wang, X., Bogen, D., Bennett, I. M., Jennings, R. M., Garcia, L., … & Ten Have, T. (2009). Linking numeracy and asthma-related quality of life. *Patient Education and Counseling, 75*(3), 386-391.

Arny, T., & Schneider, S. (2013). *Explorations: An introduction to astronomy* (7th ed.). New York, NY: McGraw-Hill.

Aud, S., Fox, M. A., & KewalRamani, A. (2010). *Status and trends in the education of racial and ethnic groups* (NCES 2010-015). Washington, DC: National Center for Education Statistics.

Bailey, T., Jeong, D. W., & Cho, S. W. (2010). Referral, enrollment, and completion in developmental education sequences in community colleges. *Economics of Education Review*, *29*(2), 255-270.

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn?: A taxonomy for far transfer. *Psychological Bulletin*, *128*(4), 612–637.

Bassok, M., & Holyoak, K. J. (1989). Interdomain transfer between isomorphic topics in algebra and physics. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *15*(1), 153.

Battle, E. S. (1965). Motivational determinants of academic task persistence. *Journal of Personality and Social Psychology*, *2*(2), 209-218.

Betne, P. (2010). Project Quantum Leap and SENCER at LaGuardia Community College. *Science Education & Civic Engagement: An International Journal, 2*(2), 12-16.

Black, A. A. J. (2005). Spatial ability and earth science conceptual understanding. *Journal of Geoscience Education*, *53*(4), 402-414.

Blair, R. (Ed.). (2006). *Beyond crossroads: Implementing mathematics standards in the first two years of college*. Memphis, TN: AMATYC.

Blair, R., Kirkman, E. E., & Maxwell, J. W. (2010). *Statistical abstract of undergraduate programs in the mathematical sciences in the United States: Fall 2010 CBMS survey*. Providence, RI: American Mathematical Society.

Bogdan, R. C. & Biklen, S. K. (2003). *Qualitative research for education: An introduction to theories and methods*. New York, NY: Pearson.

Brown, E. N., & Kass, R. E. (2009). What is statistics? (with discussion). *American Statist*, *63*, 105-123.

Brown, S. M., Culver, J. O., Osann, K. E., MacDonald, D. J., Sand, S., Thornton, A. A., … & Robson, M. E. (2011). Health literacy, numeracy, and interpretation of graphical breast cancer risk estimates. *Patient Education and Counseling, 83*(1), 92-98.

Busch, R.M., & Tasa, D. (2014). *Laboratory manual in physical geology* (10th ed.). New York, NY: Pearson.

Carnegie Foundation for the Advancement of Teaching. (2012). *Quantway*. Available from http://www.carnegiefoundation.org/quantway

Carraher, D., & Schliemann, A. (2002). The transfer dilemma. *The Journal of the Learning Sciences*, *11*(1), 1-24.

Carraher, T. N., Carraher, D. W., & Schliemann, A. D. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology, 3*(1), 21–29. Retrieved from http://doi.org/10.1111/j.2044-835X.1985.tb00951.x

Caufield, S., & Persell, C. H. (2006). Teaching social science reasoning and quantitative literacy: The role of collaborative groups. *Teaching Sociology 34*(1), 39-53.

Cavazos, J., Johnson, M. B., & Sparrow, G. S. (2010). Overcoming personal and academic challenges: Perspectives from Latina/o college students. *Journal of Hispanic Higher Education*, *9*(4), 304-316.

Ceci, S. J., & Ruiz, A. (1993). The role of context in everyday cognition. In M. Rabinowitz (Ed.), *Applied Cognition* (pp. 164 –183). Hillsdale, NJ: Erlbaum.

Chang, J. Y. (1999). Teachers college students' conceptions about evaporation, condensation, and boiling. *Science Education*, *83*(5), 511-526.

Charette, M. F., & Meng, R. (1998). The determinants of literacy and numeracy, and the effect of literacy and numeracy on labour market outcomes. *Canadian Journal of Economics*, *31*(3), 495-517.

Charles A. Dana Center. (2014). *New mathways project*. Retrieved from http://www.utdanacenter.org/higher-education/new-mathways-project/

Chouinard, R., Karsenti, T., & Roy, N. (2007). Relations among competence beliefs, utility value, achievement goals, and effort in mathematics. *British Journal of Educational Psychology*, *77*(3), 501-517.

Clyburn, G. M. (2013). Improving on the American dream: Mathematics pathways to student success. *Change: The Magazine of Higher Learning*, *45*(5), 15-23.

Cobb, P. (1988). The tension between theories of learning and instruction in mathematics education. *Educational Psychologist*, *23*(2), 87-103.

Cobb, P., & Bowers, J. (1999). Cognitive and situated learning perspectives in theory and practice. *Educational Researcher*, *28*(2), 4-15.

Cohen, D. (Ed.). (1995). *Crossroads in mathematics: Standards for introductory college mathematics before calculus*. Memphis, TN: AMATYC.

Conrad, C. F. & Serlin, R. C. (2006). *The SAGE handbook for research in education: Engaging ideas and enriching inquiry*. Thousand Oaks, CA: Sage Publications.

Couper, M. P., & Singer, E. (2009). The role of numeracy in informed consent for surveys. *Journal of Empirical Research on Human Research Ethics*, *4*(4), 17-26.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks, CA: Sage Publications.

Creswell, J. W., & Miller, T. L. (2000). Getting good qualitative data. *Theory into Practice*, *39*(3), 124-130.

Crockcroft, W. H. 1982. *Mathematics counts*. London, UK: HM Stationery Office.

Cullinane, J., & Treisman, P. U. (2010). *Improving developmental mathematics education in community colleges: A prospectus and early progress report on the Quantway Initiative* (NCPR working paper). New York, NY: National Center for Postsecondary Research.

Denzin, N. K. (2001). The reflexive interview and a performative social science. *Qualitative Research*, *1*(1), 23-46.

Department of Education and Science (DES). (1959). *15 to 18* (The Crowther report). London, UK: HM Stationery Office.

Detterman, D. K. (1993). The case for the prosecution: Transfer as an epiphenomenon. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 1-24). Westport, CT: Ablex Publishing.

Dewey, J. (1909). *Moral principles in education*. Boston, MA: Houghton Mifflin.

Dingman, S. W., & Madison, B. L. (2010). Quantitative reasoning in the contemporary world, 1: The course and its challenges. *Numeracy*, *3*(2), 4.

Downs, R. M., & Liben, L. S. (1991). The development of expertise in geography: A cognitive-developmental approach to geographic education. *Annals of the Association of American Geographers*, *81*(2), 304-327.

Doyle, W. (1988). Work in mathematics classes: The context of students' thinking during instruction. *Educational Psychologist*, *23*(2), 167-180.

Durkheim, E. (1938). *The rules of sociological method* (8th ed.). Glencoe, IL: The Free Press.

Dyche, S., McClurg, P., Stepans, J., & Veath, M. L. (1993). Questions and conjectures concerning models, misconceptions, and spatial ability. *School Science and Mathematics*, *93*(4), 191-197.

Erlwanger, S. H. (1973). Benny's conception of rules and answers in IPI mathematics. *Journal of Children's Mathematical Behavior*, *1*(2), 7-26.

Estry, D. W., & Ferrini-Mundy, J. (2005). *Quantitative literacy task force final report and recommendations*. East Lansing, MI: Michigan State University.

Felbrich, A., Müller, C., & Blömeke, S. (2008). Epistemological beliefs concerning the nature of mathematics among teacher educators and teacher education students in mathematics. *ZDM*, *40*(5), 763–776.

FitzSimons, G. E. (2002). *What counts as mathematics?: Technologies of power in adult and vocational education*. New York, NY: Kluwer Academic Publishers.

Follette, K. B., McCarthy, D. W., Dokter, E., Buxner, S., & Prather, E. (2015). The Quantitative Reasoning for College Science (QuaRCS) assessment, 1: Development and validation. *Numeracy, 8*(2), 2.

Frith, V. (2011). Quantitative literacy provision in the first year of medical studies. *South African Journal of Higher Education, 25*(4), 725-740.

Frith, V. (2012). A quantitative literacy course for Humanities and Law students: The challenges of a context-based curriculum. *Perspectives in Education*, *30*(2), 41-49.

Frith, V., & Gunston, G. (2011). Towards understanding the quantitative literacy demands of a first-year medical curriculum. *African Journal of Health Professions Education*, *3*(1), 19-23.

Frith, V., Le Roux, K., Lloyd, P., Jaftha, J., Mhakure, D., & Rughubar-Reddy, S. (2010). Tensions between context and content in a quantitative literacy course at university. In U. Gellert, E. Jablonka, & C. Morgan (Eds.), *Proceedings of the sixth mathematics education and society conference* (pp. 230-240). Berlin: Freie Universität Berlin.

Frith, V., & Prince, R. (2009). A framework for understanding the quantitative literacy demands of higher education. *South African Journal of Higher Education*, *23*(1), 83-97.

Gal, I. (1993). *Issues and challenges in adult numeracy* (Technical report TR93-15). Philadelphia, PA: National Center on Adult Literacy.

Gal, I. (1997). Numeracy: Imperatives of a forgotten goal. In L.A. Steen (Ed.), *Why numbers count: quantitative literacy for tomorrow's America* (pp. 36-44). New York, NY: The College Board.

Ganter, S. L., & Barker, W. (Eds.). (2004). *The curriculum foundations project: Voices of the partner disciplines*. Washington, DC: Mathematical Association of America.

Ganter, S. L., & Haver, B. (2011). Responding to the recommendations of the Curriculum Foundations Project. In S. L. Ganter & B. Haver (Eds.), *Partner discipline recommendations for introductory college mathematics and the implications for College Algebra*, (pp. 39-41). Washington, DC: Mathematical Association of America.

Geertz, C. (1973). *The interpretation of cultures: Selected essays* (Vol. 5019). New York, NY: Basic Books.

Gerardi, K., Goette, L., & Meier, S. (2013). Numerical ability predicts mortgage default. *Proceedings of the National Academy of Sciences*, *110*(28), 11267-11271.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology*, *12*(3), 306-355.

Glaser, B. (2004). "Naturalist inquiry" and grounded theory. *Forum Qualitative Sozialforschung, 5*(1), 7.

Glesne, C. (2011). *Becoming qualitative researchers: An introduction*. Boston: Pearson.

Goldrick-Rab, S. (2010). Challenges and opportunities for improving community college student success. *Review of Educational Research*, *80*(3), 437–469.

Goodlad, J. I. (1979). *Curriculum inquiry: The study of curriculum practice*. New York, NY: McGraw-Hill.

Grawe, N. D. (2011). The potential for teaching quantitative reasoning across the curriculum: Empirical evidence. *International Journal for the Scholarship of Teaching and Learning*, *5*(1), 14.

Greeno, J. G. (1991). Number sense as situated knowing in a conceptual domain. *Journal for Research in Mathematics Education*, *22*, 170-218.

Greeno, J. G. (1997). Theories and practices of thinking and learning to think. *American Journal of Education*, 106(1), 85–126.

Greeno, J. G., Smith, D. R., & Moore, J. L. (1993). Transfer of situated learning. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 99 – 167). Westport, CT: Ablex Publishing.

Guba, E. G., & Lincoln, Y. S. (1981). *Effective evaluation: Improving the usefulness of evaluation results through responsive and naturalistic approaches*. San Francisco, CA: Jossey-Bass.

Hagedorn, L. S., & DuBray, D. (2010). Math and science success and nonsuccess: Journeys within the community college. *Journal of Women and Minorities in Science and Engineering*, *16*(1), 31–50.

Halpern, D. F. (1998). Teaching critical thinking for transfer across domains: Disposition, skills, structure training, and metacognitive monitoring. *American Psychologist*, *53*(4), 449.

Hathcoat, J. D., Sundre, D. L., & Johnston, M. M. (2015). Assessing college students' quantitative and scientific reasoning: The James Madison University story. *Numeracy*, *8*(1), 2.

Hayden, R. W. (2004). Planning a statistical literacy program at the college level: Musings and a bibliography. *ASA 2004 Proceedings of the Section on Statistical Education*. Retrieved from http://www.statlit.org/PDF/2004HaydenASA.pdf

Hempel, C. G. (1965). *Aspects of scientific explanation*. New York, NY: The Free Press.

Henningsen, M., & Stein, M. K. (1997). Mathematical tasks and student cognition: Classroom-based factors that support and inhibit high-level mathematical thinking and reasoning. *Journal for Research in Mathematics Education*, *28*(5), 524-549.

Hern, K., & Snell, M. (2010). *Exponential attrition and the promise of acceleration in developmental English and math*. Berkeley, CA: The Research and Planning Group for California Community Colleges. Retrieved from http://rpgroup.org/resources/accelerated-developmental-english-and-math

Hess, D., & Tasa, D. (2013). *McKnight's physical geography: A landscape approach* (11th ed.). Upper Saddle River, NJ: Prentice Hall.

Hester, S., Buxner, S., Elfring, L., & Nagy, L. (2014). Integrating quantitative thinking into an introductory biology course improves students' mathematical reasoning in biological contexts. *CBE-Life Sciences Education*, *13*(1), 54-64.

Hiebert, J., Carpenter, T. P., Fennema, E., Fuson, K., Human, P., Murray, H., ... & Wearne, D. (1996). Problem solving as a basis for reform in curriculum and instruction: The case of mathematics. *Educational Researcher*, *25*(4), 12-21.

Hiebert, J., & Lefevre, P. (1986). Conceptual and procedural knowledge for teaching on student achievement. In J. Hiebert (Ed.), *Conceptual and procedural knowledge: the case of mathematics* (pp. 1-27). Hillsdale, NJ: Erlbaum.

Howington, H., Hartfield, T., & Hillyard, C. (2015). Faculty viewpoints on teaching Quantway®. *Numeracy*, *8*(1), 10.

Hughes-Hallett, D. H. (2001). Achieving numeracy: The challenge of implementation. In L. A. Steen (Ed.), *Mathematics and democracy: The case for quantitative literacy* (pp. 93-98). Princeton, NJ: National Council on Education and the Disciplines.

Hughes-Hallett, D. H. (2003). The role of mathematics courses in the development of quantitative literacy. In B. L. Madison and L. A. Steen (Eds.), *Quantitative literacy: Why numeracy matters for schools and colleges* (pp. 91-98). Princeton, NJ: National Council on Education and the Disciplines.

Hume, D. (1896) *A treatise of human nature*. L.A. Selby-Bigge (Ed.). Oxford, UK: Clarendon Press. Retrieved from http://oll.libertyfund.org/titles/342

Jansen, A. (2011, October). How do students create opportunities to learn mathematics?: Representing students in research on curriculum use. In L. R. Wiest & T. d. Lamberg (Eds.), *Proceedings of the thirty-third annual conference of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 70-78). Reno, NV: University of Nevada, Reno.

Johnston, B. (2007). Critical numeracy?. In S. Kelly, B. Johnston, & K. Yasukawa (Eds.), *The adult numeracy handbook: Reframing adult numeracy in Australia* (pp. 50–56). Sydney, NSW: Adult Literacy and Numeracy Australian Research Consortium.

Judd, C. H. (1908). The relation of special training to general intelligence. *Educational Review*, *36*, 28-42.

Kahneman, D. (2011). *Thinking, fast and slow*. New York, NY: Macmillan.

Kaput, J. (1998). Transforming algebra from an engine of inequity to an engine of mathematical power by "algebrafying" the K-12 curriculum. In National Council of Teachers of Mathematics & Mathematical Sciences Education Board (Eds.), *The nature and role of algebra in the K-14 curriculum: Proceedings of a national symposium* (pp. 25–26). Washington, DC: National Research Council, National Academy Press.

Karaali, G., Villafane Hernandez, E. H., & Taylor, J. A. (2016). What's in a name? A critical review of definitions of quantitative literacy, numeracy, and quantitative reasoning, *Numeracy, 9*(1), 2.

Karp, D. A. (2001). *The burden of sympathy: Caring for the mentally ill and boundaries of obligation*. New York, NY: Oxford University Press.

Kirsch, R. J., Leathers, P. E., & Snead, K. C. (1993). Student versus recruiter perceptions of the importance of staff auditor performance variables. *Accounting Horizons*, *7*(4), 58-69.

Krueger, R.A., & Casey, M.A. (2009). *Focus groups: A practical guide for applied research* (4th ed.). Thousand Oaks, CA: Sage Publications.

Lake, D. (1999). Helping students to go SOLO: Teaching critical numeracy in the biological sciences. *Journal of Biological Education*, *33*(4), 191-198.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge, UK: Cambridge University Press.

Leinhardt, G., Zaslavsky, O., & Stein, M. K. (1990). Functions, graphs, and graphing: Tasks, learning, and teaching. *Review of Educational Research*, *60*(1), 1-64.

Levitt, S., & Dubner, S. J. (2009). *Superfreakonomics: Global cooling, patriotic prostitutes, and why suicide bombers should buy life insurance*. New York, NY: HarperCollins.

Liamputtong, P. (2011). *Focus group methodology: Principle and practice*. Thousand Oaks, CA: Sage Publications.

Lincoln, Y. S. & Guba, E. G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage Publications.

Lincoln, Y. S., & Guba, E. G. (1986). But is it rigorous? Trustworthiness and authenticity in naturalistic evaluation. *New Directions for Program Evaluation*, *1986*(30), 73-84.

Lobato, J. (1996). Transfer reconceived: How "sameness" is produced in mathematical activity (Doctoral dissertation, University of California, Berkeley). *Dissertation Abstracts International*, *58*(02), 406.

Lobato, J. (2006). Alternative perspectives on the transfer of learning: History, issues, and challenges for future research. *The Journal of the Learning Sciences*, *15*(4), 431-449.

Lobato, J., & Siebert, D. (2002). Quantitative reasoning in a reconceived view of transfer. *The Journal of Mathematical Behavior*, *21*(1), 87-116.

Locke, E. A., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American Psychologist*, *57*(9), 705-717.

Maaß, K. (2006). What are modelling competencies?. *ZDM*, *38*(2), 113-142.

Macdonald, R. H., & Bailey, C. M. (2000). Integrating the teaching of quantitative skills across the geology curriculum in a department. *Journal of Geoscience Education*, *48*(4), 482-486.

Marieb, E. & Hoehn, K. (2012). *Human anatomy and physiology* (9th ed.). SanFransisco, CA: Pearson.

Mason, J. (1996). *Qualitative researching*. Thousand Oaks, CA: Sage Publications.

Maxwell, J. A. (2012). *Qualitative research design: An interactive approach*. Thousand Oaks, CA: Sage Publications.

Mayes, R. L., Peterson, F., & Bonilla, R. (2013). Quantitative reasoning learning progressions for environmental science: Developing a framework. *Numeracy*, *6*(1), 4.

McClure, R., & Sircar, S. (2008). Quantitative literacy for undergraduate business students in the 21st century. *Journal of Education for Business*, *83*(6), 369-374.

Medsker, L. (1960). *The junior college: Progress and prospect.* New York, NY: McGraw-Hill.

Merriam, S. B. (1998). *Qualitative research and case study applications in education.* San Francisco, CA: Jossey-Bass Publishers.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. San Francisco, CA: Jossey-Bass.

Merriam, S. B. (2014). Qualitative research: Designing, implementing, and publishing a study. In V. C. X. Wang (Ed.), *Handbook of research on scholarly publishing and research methods* (pp. 125-140). Hershey, PA: Information Science Reference.

Mesa, V. (2007). *The teaching of mathematics in community colleges* (Unpublished manuscript). Ann Arbor, MI: University of Michigan.

Mesa, V. (2012). Achievement goal orientations of community college mathematics students and the misalignment of instructor perceptions. *Community College Review*, *40*(1), 46–74. http://doi.org/10.1177/0091552111435663

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks, CA: Sage Publications.

Miller, J. D. (1983). Scientific literacy: A conceptual and empirical review. *Daedalus*, *112*(2), 29-48.

Miller, J. D. (2010). Civic scientific literacy: The role of the media in the electronic era. In D. Kennedy & G. Overholser (Eds.), *Science and the media* (pp. 44-61). Cambridge, MA: American Academy of Arts and Sciences.

Miller, J. D. (2010). The conceptualization and measurement of civic scientific literacy for the twenty-first century. In J. Meinwald & J. G. Hildebrand, *Science and the educated American: A core component of liberal education* (pp. 241-255). Cambridge, MA: American Academy of Arts and Sciences.

Mtetwa, D., & Garofalo, J. (1989). Beliefs about mathematics: An overlooked aspect of student difficulties. *Academic Therapy*, *24*(5), 611-618.

Mulhern, G., & Wylie, J. (2004). Changing levels of numeracy and other core mathematical skills among psychology undergraduates between 1992 and 2002. *British Journal of Psychology*, *95*(3), 355-370.

National Council of Teachers of Mathematics (NCTM). (2000). *Principles and standards for school mathematics*. Reston, VA: NCTM.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by state*s. Washington, DC: The National Academies Press.

Núñez, R. E., Edwards, L. D., & Matos, J. F. (1999). Embodied cognition as grounding for situatedness and context in mathematics education. *Educational Studies in Mathematics*, *39*(1-3), 45-65.

OpenStax College (2013). *Concepts of biology*. Available from http://cnx.org/content/col11487/latest/

Patton, M. Q. (1990). *Qualitative evaluation and research methods*. Thousand Oaks, CA: Sage Publications.

Pea, R. D. (1987). Socializing the knowledge transfer problem. *International Journal of Educational Research, 11*, 639-663.

Phoenix, D. A. (1999). Numeracy and the life scientist!. *Journal of Biological Education, 34*(1), 3-4.

Powell, W., & Leveson, D. (2004). The unique role of introductory geology courses in teaching quantitative reasoning. *Journal of Geoscience Education*, *52*(3), 301-305.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning?. *Educational Researcher*, *29*(1), 4-15.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research*, *75*(2), 211-246.

Reed, S. K. (1974). Structural descriptions and the limitations of visual images. *Memory & Cognition*, *2*(2), 329-336.

Riege, A. M. (2003). Validity and reliability tests in case study research: A literature review with "hands-on" applications for each research phase. *Qualitative Market Research: An International Journal*, *6*(2), 75-86.

Rheinlander, K., & Wallace, D. (2011). Calculus, biology and medicine: A case study in quantitative literacy for science students. *Numeracy*, *4*(1), 3.

Rotman, J. (2013). Inside new life: A grand vision for developmental mathematics. *MathAMATYC Educator*, *4*(3), 27-35.

Rutherford, F. J., & Ahlgren, A. (1991). *Science for all Americans.* New York, NY: Oxford University Press.

Sally, P. (2003, January). *Is teaching about mathematics the same as teaching mathematics?*. MAA Invited Address presented at the Joint Mathematics Meetings, Baltimore, MD.

Schapira, M. M., Fletcher, K. E., Gilligan, M. A., King, T. K., Laud, P. W., Matthews, B. A., ... & Hayes, E. (2008). A framework for health numeracy: how patients use quantitative skills in health care. *Journal of Health Communication*, *13*(5), 501-517.

Schooler, C. (1989). Social structure effects and experimental situations: Mutual lessons of cognitive and social science. In K. W. Schaie & C. Schooler (Eds.), *Social structure and aging: Psychological processes* (pp. 131-141). Hillsdale, NJ: Erlbaum.

Schram, T. H. (2003). *Conceptualizing qualitative inquiry: Mindwork for fieldwork in education and the social sciences*. Upper Saddle River, N.J: Merrill/Prentice Hall.

Schwandt, T. A. (1997). *Qualitative inquiry: A dictionary of terms*. Thousand Oaks, CA: Sage Publications.

Schwandt, T.A. (2000). Three epistemological stances for qualitative inquiry: Interpretivism, hermeneutics, and social constructionism. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed., pp. 189-213). Thousand Oaks, CA: Sage Publications.

Schwartz, L. M., Woloshin, S., Black, W. C., & Welch, H. G. (1997). The role of numeracy in understanding the benefit of screening mammography. *Annals of Internal Medicine, 127*(11), 966-972.

Shamos, M. H. (1995). *The myth of scientific literacy*. New Brunswick, NJ: Rutgers University Press.

Slater, T., & Adams, J. (2002). Mathematical reasoning over arithmetic in introductory astronomy. *The Physics Teacher*, *40*(5), 268-271.

Smith, J., & Thompson, P. W. (2007). Quantitative reasoning and the development of algebraic reasoning. In J. J. Kaput, D. W. Carraher, & M. L. Blanton (Eds.), *Algebra in the early grades* (pp. 95-132). New York, NY: Erlbaum.

Speth, E. B., Momsen, J. L., Moyerbrailean, G. A., Ebert-May, D., Long, T. M., Wyse, S., & Linton, D. (2010). 1, 2, 3, 4: Infusing quantitative literacy into introductory biology. *CBE-Life Sciences Education*, *9*(3), 323-332.

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage Publications.

Steele, B., & Kiliç-Bahi, S. (2008). Quantitative literacy across the curriculum: A case study. *Numeracy*, *1*(2), 3.

Steen, L. A.. (1990). Numeracy. *Daedalus*, *119*(2), 211–231. Retrieved from http://www.jstor.org/stable/20025307

Steen, L. A. (2001). Embracing numeracy. In L. A. Steen (Ed.), *Mathematics and democracy: The case for quantitative literacy* (pp. 107-116). Princeton, NJ: National Council on Education and the Disciplines.

Steen, L. A. (2003). Data, shapes, symbols: Achieving balance in school mathematics. In B. Madison & L. A. Steen (Eds.), *Quantitative literacy: Why numeracy matters for schools and colleges* (pp. 53-74). Princeton, NJ: National Council on Education and the Disciplines.

Steen, L. A. (2004). *Achieving quantitative literacy: An urgent challenge for higher education* (MAA Notes No. 62). Washington, DC: Mathematical Association of America.

Stein, M. K., Engle, R. A., Smith, M. S., & Hughes, E. K. (2008). Orchestrating productive mathematical discussions: Five practices for helping teachers move beyond show and tell. *Mathematical Thinking and Learning*, *10*(4), 313-340.

Stein, M. K., Grover, B. W., & Henningsen, M. (1996). Building student capacity for mathematical thinking and reasoning: An analysis of mathematical tasks used in reform classrooms. *American Educational Research Journal*, *33*(2), 455-488.

Thorndike, E. L. (1912). *Education, a first book*. New York, NY: Macmillan.

Trefil, J., & Hazen, R. M. (2010). Scientific literacy: A modest proposal. In J. Meinwald & J. G. Hildebrand, *Science and the educated American: A core component of liberal education*, (pp. 57-69). Cambridge, MA: American Academy of Arts and Sciences.

Usiskin, Z. (1999). Conceptions of school algebra and uses of variables. In B. Moses (Ed.), *Algebraic thinking, grades K-12: Readings from NCTM's school-based journals and other publications* (pp. 7–13). Reston, VA: National Council of Teachers of Mathematics.

Vacher, H. L. (2014). Looking at the multiple meanings of numeracy, quantitative literacy, and quantitative reasoning. *Numeracy*, *7*(2), 1.

Vygotskiĭ, L. S. (1978). *Mind in society: The development of higher psychological processes*. M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.). Cambridge: Harvard University Press.

Weber, M. (1949). *The methodology of the social sciences*. Wilmington, IL: The Free Press.

Whitehead, A. N. (1929). *The aims of education and other essays*. New York, NY: Macmillan.

Wiggins, G. (2003). Get real!: Assessing for quantitative literacy. In B. L. Madison & L. A. Steen (Eds.), *Quantitative literacy: Why numeracy matters for schools and colleges* (pp. 121-143). Princeton, NJ: National Council on Education and the Disciplines.

Wittrock, M. C. (Ed.). (1986). *Handbook of research on teaching* (3rd ed.). New York, NY: Macmillan.

Wolfe, C. R. (1993). Quantitative reasoning across a college curriculum. *College Teaching*, *41*(1), 3-9.

Yin, R. K. (2013). *Case study research: Design and methods*. Thousand Oaks, CA: Sage Publications.